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COMPARATIVE PERFORMANCE ANALYSIS OF VSA AND GWO TECHNIQUES FOR LOAD FREQUENCY CONTROL OF SINGLE AREA FUEL CELL MICROGRID

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Abstract. In this paper, the frequency control of a single area micro grid system is studied. Recently, the dynamic performance of micro-grid systems can be enhanced by effective load frequency control which is one of the most important aspects. The system having a fuel cell, micro turbine, diesel generator, battery energy storage system and flywheel energy storage system is modeled. To optimize the dynamic performance of the system, Vortex Search Algorithm (VSA) and Grey Wolf Optimizer (GWO) are used. Additionally, a cascade PD-PI controller is also applied to the system for enhancing the performance. The results are analyzed with respect to overshoot, undershoot and settling time. It can be clearly observed from the results that GWO algorithm provides better system performance for selected micro-grid system.

Keywords: Load frequency control, micro grid, vortex search algorithm, grey wolf optimizer

СРАВНИТЕЛЬНЫЙ АНАЛИЗ ЭФФЕКТИВНОСТИ МЕТОДОВ VSA И GWO ДЛЯ КОНТРОЛЯ ЧАСТОТЫ НАГРУЗКИ ОДНОЗОННОГО ТОПЛИВНОГО ЭЛЕМЕНТА МИКРОСЕТЕВОЙ СИСТЕМЫ

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В данной статье рассматривается частотное регулирование отдельной микросетевой системы. В последнее время динамические характеристики микросетевых систем могут быть улучшены за счет эффективного управления частоты нагрузки, что является одним из наиболее важных аспектов.

Смоделирована система, имеющая топливный элемент, микротурбину, дизельный генератор, аккумуляторную систему накопления энергии и систему маховичного накопителя энергии. Для оптимизации динамических характеристик системы используются алгоритм поиска вихрей (VSA) и оптимизатор серого волка (GWO). Кроме того, для повышения производительности в системе также применяется каскадный контроллер PD-PI. Результаты анализируются относительно времени перерегулирования, недорегулирования и

установления. Из результатов ясно видно, что алгоритм GWO обеспечивает лучшую производительность системы для выбранной микросетевой системы.

Ключевые слова: контроль частоты нагрузки, микросетевая система, алгоритм поиска вихрей, оптимизатор серого волка

Introduction: Conventional electrical power systems are mainly consist of large number of components. Therefore, transmission of generated power from generation units to the over distance last consumer reduces the transmission efficiency [1]. In parallel, these power systems mostly use fossil fuels to provide as energy resources. The transfer of energy to long distances causes an increase in the fossil fuels used as well.

In the globalizing world, traditional power systems are gradually being replaced by modern power systems [2,3]. Micro-grid systems can be considered as modern power systems. These systems usually contain non-fossil source (such as fuel cell, battery systems) and renewable energy sources (such as wind turbines, solar panels).

As with conventional power systems, load frequency control is also a very important requirement for micro-grid systems. The main objective of load frequency control can be considered as follows;

1) Keep the system frequency specific band width limits [4],
2) Deviation of frequency made zero or closest to zero [5],

In this study, VSA [6] and GWO [7] are applied to the selected micro-grid system to optimize load frequency control performances of the system. The frequency deviation obtained by both algorithms are compared in terms of overshoot, undershoot and settling times. Moreover, cascade PD-PD controller is used in these analyzes. This controller type consists of combination of PD controller and PI controller.

This paper is organized as follows: In section 2, micro-grid model for load frequency control, VSA and GWO are briefly mentioned. In section 3, obtained results are illustrated. In section 4, Conclusions are given.

Material and Methods

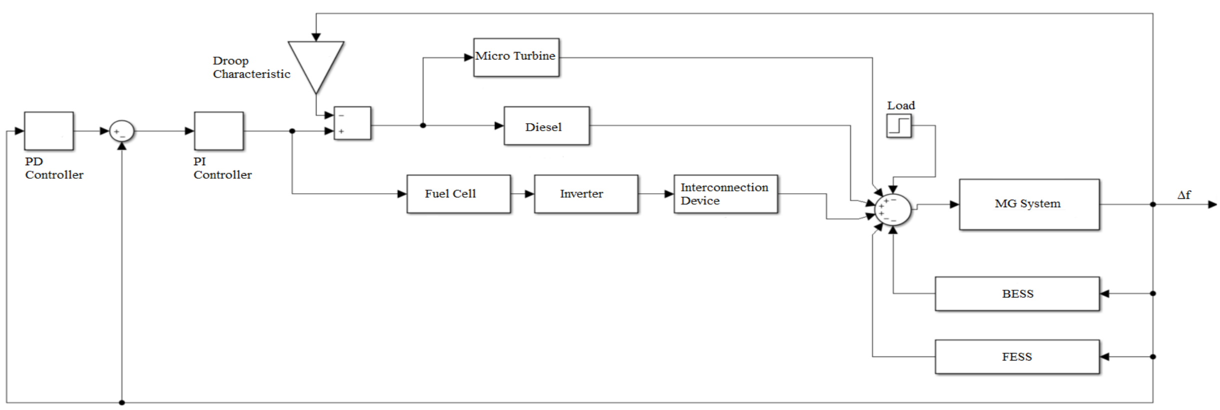

Fig. 1. Micro grid model for LFC analyzes

I. Micro grid model for load frequency control: Load frequency control is essential control

for micro grid power systems. The micro grid model used in this study is given in Figure 1. This model have micro turbine block, diesel generator block, battery energy storage system (BESS) block, flywheel energy storage system (FESS) block, micro grid (MG) system block, fuel cell, inverter block, connection device block and droop characteristic block.

In this model, PD controller can be defined as follows:

$$PD = k_{pd} + sk_d \tag{1}$$

Where, k_{pd} and k_d proportional and derivative gain of PD controller. PI controller can be defined as follows:

$$PI = k_{pi} + \frac{k_i}{s} \tag{2}$$

Where, k_{pi} and k_i proportional and integral gain of PI controller. Drop characteristic can be defined as follows:

$$Drop\ Characteristic = \frac{1}{R} \tag{3}$$

Micro turbine can be defined as follows [8]:

$$\frac{1}{1+sT_{MT}} \tag{4}$$

Where, T_{MT} is time constant of micro turbine. Diesel can be defined as follows [8]:

$$\frac{1}{1+sT_D} \tag{5}$$

Where, T_D is time constant of diesel. Fuel cell can be defined as follows [2]:

$$\frac{1}{1+sT_{FC}} \tag{6}$$

Where, T_{FC} is time constant of fuel cell. Inverter can be defined as follows [2]:

$$\frac{1}{1+sT_I} \tag{7}$$

Where, T_I is time constant of inverter. Connection device can be defined as follows [2]:

$$\frac{1}{1+sT_{CD}} \tag{8}$$

Where, T_{CD} is time constant of connection device. MG system can be defined as follows [2]:

$$\frac{1}{Ms+D} \tag{9}$$

Where, M is inertia constant and D is damping coefficient respectively. BESS can be defined as follows [8]:

$$\frac{1}{1+sT_{BESS}} \tag{10}$$

Where, T_{BESS} is time constant of battery energy storage system. FESS can be defined as follows [2]:

$$\frac{1}{1+sT_{FESS}} \tag{11}$$

Where, T_{FESS} is time constant of flywheel energy storage system. In this study, ITSE (integral time square error) is used as objective function in GWO and VSA techniques. ITSE can be defined as following equation:

$$ITSE = \int (time \times (error)^2)dt \tag{12}$$

II. Vortex Search Algorithm: VSO is developed by B. Dogan and T. Olmez in 2014 [6]. This algorithm has good balance between exploration and exploitation behavior. For this reason, the optimal results can be reliably found. The shape of the mixed liquids inspired the development of the VSA [6].

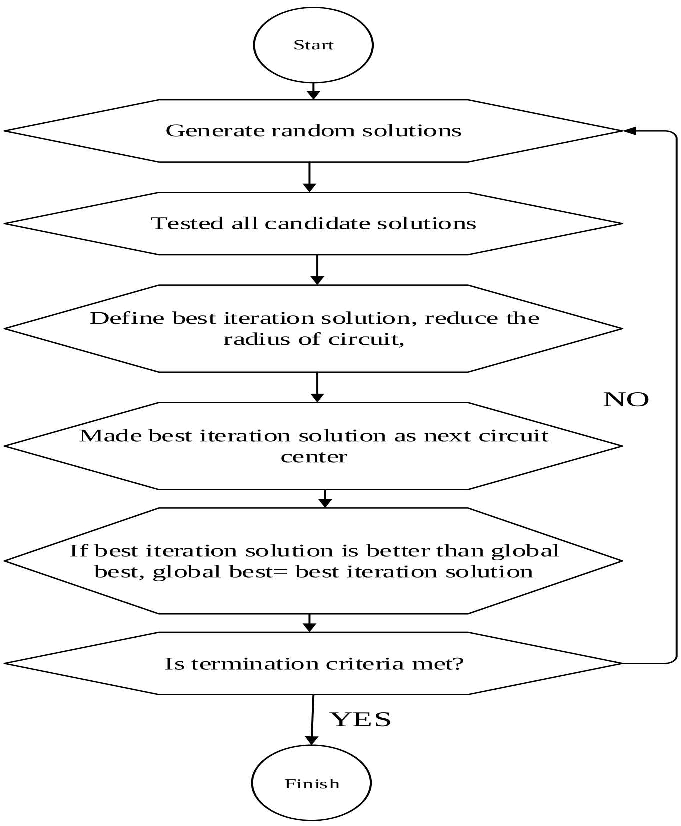

Fig. 2. Flow chart of VSA

In this technique, candidate solutions are formed in the first circuit. All candidate solutions are controlled for the problem and the best one (iteration best) is determined from these and defined as global best solution. Founded iteration best solution is defined as the center of the next circuit. After then, radius of the circuit is decreased. New iteration best solution is compared with the previous best iteration's solution. If new iteration best solution has minimum value rather than previous best iteration solution, new iteration best solution is defined as global best solution.

This process continues until the termination criterion is met. Basically flow diagram of VSA is illustrated in Figure 2.

III. Grey Wolf Optimizer: GWO is developed by S. Mirjalili et al. in 2014 [7]. This technique has very good capability to search of parameter space. Grey wolves are inspired the development of the GWO [7].

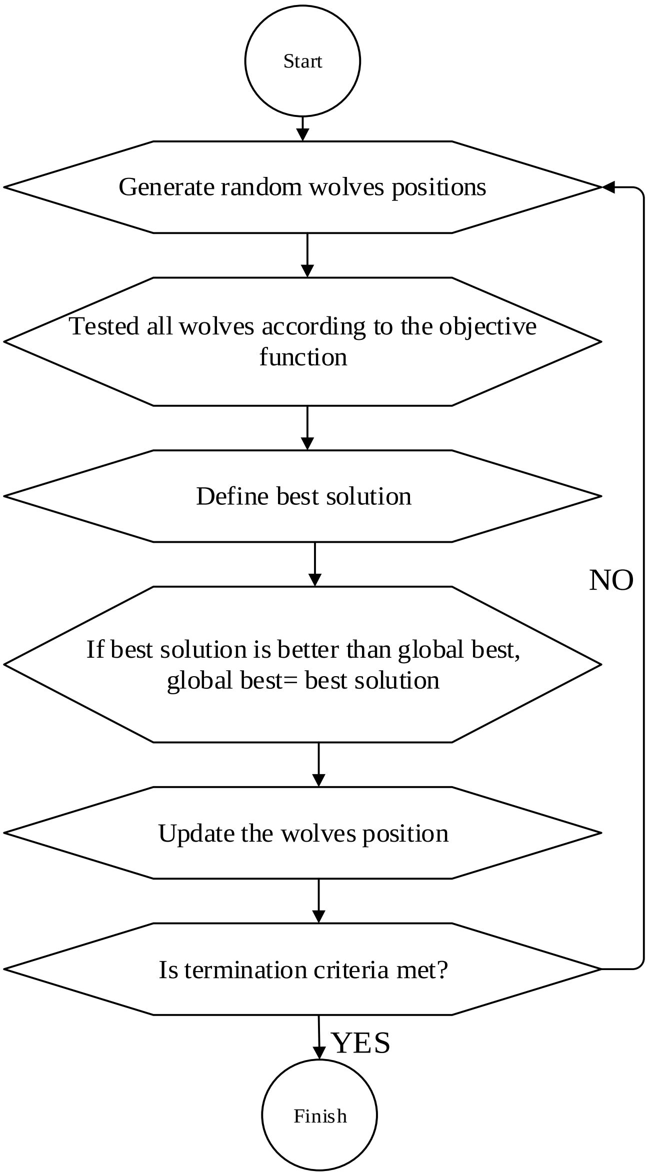

Fig. 3. Flow chart of GWO

In this method, positions of grey wolves (candidate solutions) are formed randomly. These candidate solutions are search the space for obtained minimum objective function for the problem.

After the iteration, best iteration values are determined and then the positions of candidate solution are updated. If the best iteration value in the next iteration is better than the previous best iteration value, the best iteration value in the next iteration is defined as the global best value.

This process continues until the termination criterion is met. Basically flow diagram of GWO is shown in Figure 3.

Results and Analysis: In this section, comparative performance results of VSA and GWO are discussed. Micro grid system parameters are given in Table 1. In this system, some parameters are taken from the reference [2], while some parameters are taken from the reference [8].

Table 1: Parameters of micro grid system

R	**T_{MT}**	**T_D**	**M**	**D**
0.05	2	2	0.1667	0.015
T_{FC}	**T_I**	**T_{CD}**	**T_{BESS}**	**T_{FESS}**
0.26	0.04	0.004	0.1	0.1

The cascade PD-PI controller parameters with VSA and GWO are given in Table 2:

Table 2: Controller parameters

	k_{pi}	**k_i**	**k_{pd}**	**k_d**
VSA	-1.7945	-4.9489	4.9499	2.3019
GWO	2.8522	4.9500	-4.7296	-1.4668

Frequency deviations outputs are illustrated in Figure 4:

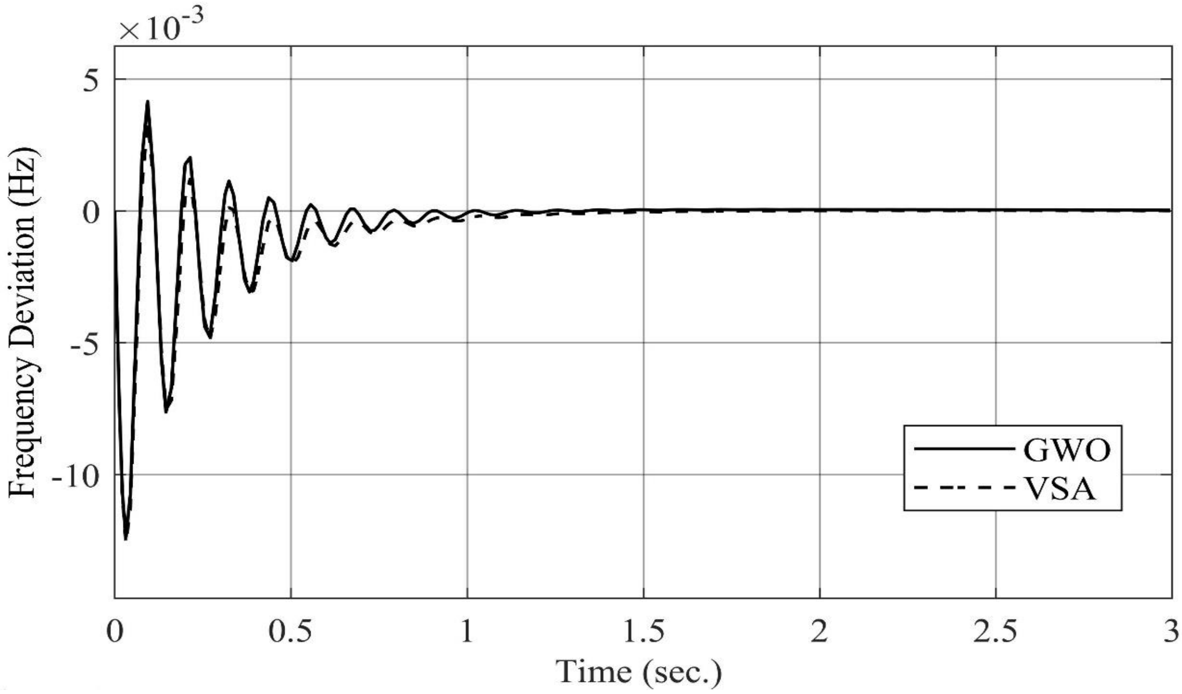

Fig. 4: Comparative frequency deviation graphic

From this figure, it is clear that the obtained two frequency deviation outputs with VSA and GWO are close to each other. However, the oscillation amplitude of GWO is slightly larger compared to VSA. Obtained numerical overshoot, undershoot and settling time results are given in Table 3.

Table 3: Comparative performance results

	Overshoot	**Undershoot**	**Settling time (0.002 band with)**
VSA	**3.411e-3**	-1.258e-2	0.5054
GWO	4.157e-3	**-1.236e-2**	**0.4020**

It is clearly seen that from this table, although VSA gave minimum overshoot value, GWO gave minimum settling time and undershoot values.

Conclusions: In this paper, load frequency control of single area having fuel cell micro grid system is examined. Comparative performance results performed with VSA and GWO methods. Overshoot value obtained by VSA approximately %17.94 lower than GWO. However, GWO gave approximately %1.75 lower undershoot and % 20.46 lower settling time value than VSA. It can be said that from the obtained results, GWO has the ability to give better performance.

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THREE-PHASE TWO-STROKE ELECTROMAGNETIC VIBRATION DEVICE MANAGING OUTPUT PARAMETERS

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Annotation. It is known that the stable operation of existing three-phase low mechanical frequency electromagnetic type vibrating devices depends on keeping the specific frequencies of the electrical and mechanical systems at the same value or close to each other. In the work process, the specific frequency of the mechanical system is variable depending on the mass, while the specific frequency of the electrical system remains practically constant. This causes unstable operation of the electromechanical system of the vibration device. In order to overcome this deficiency, the article considers the issue of expanding the frequency interval of the amplitude-frequency characteristic of the electrical system.

Keywords: low mechanical frequency electromagnetic vibrator, factor of quality, frequency characteristic, stable operation, output parameters.

ÜÇFAZALI İKİTAKTLI ELEKTROMAQNİT VİBRASİYA QURĞUSUNUN ÇIXIŞ PARAMETRLƏRİNİN İDARƏ OLUNMASI

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Annotasiya. Məlumdur ki, mövcud üçfazalı alçaq mexaniki tezlikli elektromaqnit tipli vibrotəsirləndirici qurğular dayanıqlı işi elektrik və mexaniki sistemlərin məxsusi tezliklərinin eyni və ya bir-birinə yaxın qiymətdə saxlanmasından asılıdır. İş prosesində mexaniki sistemin məxsusi tezliyi kütlədən asılı dəyişən olur, elektrik sistemin məxsusi tezliyi isə praktik olaraq sabit qalır. Bu isə vibrasiya qurğusunun elektromexaniki sisteminin dayanıqsız işləməsinə səbəb olur. Bu çatışmazlığı aradan qaldırmaq üçün məqalədə elektrik sistemin amplitud-tezlik xarakteristikasının tezlik intervalını genişləndirilməsi məsələsinə baxılır.

Açar sözlər: alçaq mexaniki tezlikli elektromaqnit vibrator, keyfiyyətlilik əmsalı, tezlik xarakteristikası, dayanıqlı iş, çıxış parametrləri.

УПРАВЛЕНИЕ ВЫХОДНЫМИ ПАРАМЕТРАМИ ТРЕХФАЗНОГО ДВУХТАКТНОГО ЭЛЕКТРОМАГНИТНОГО ВИБРОУСТРОЙСТВО

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Аннотация. Известно, что устойчивая работа существующих трехфазных

низкочастотных вибрационных устройств электромагнитного типа зависит от поддержания конкретных частот электрической и механической систем на одном и том же значении или близких друг к другу. В процессе работы удельная частота механической системы изменяется в зависимости от нагрузку, тогда как удельная частота электрической системы остается практически постоянной. Это вызывает нестабильную работу электромеханической системы вибрационного устройства. С целью преодоления этого недостатка в статье рассматривается вопрос расширения частотного интервала амплитудно-частотной характеристики электромеханической системы устройства.

Ключевые слова: электромагнитный вибратор низкомеханической частоты, добротность, частотная характеристика, устойчивая работа, выходные параметры.

INTRODUCTİON

In many areas of the industry, the application of vibration devices is widely used in the means of transportation of finished products, their orientation, mixing, acceleration of chemical reactions and other such processes. Since vibration devices are used in all areas of the economy, they have a very diverse construction and functional capabilities in a wide power range. The requirement of technological processes for vibration devices is that their mechanical frequency is in the required interval and stable operation of the system is ensured in this interval..

Depending on the values of the mechanical frequency and operating amplitude, their control interval, various vibrators are used in technological processes in various fields of industry. The high and low values of the mechanical frequency in such devices are very different depending on the place of application. There are areas of technological processes in which the use of a low mechanical frequency interval (up to 20 Hs) is of great importance [1-4]. Currently, the demand for the creation of vibratory devices whose mechanical system operates in the low frequency range is increasing day by day.

It is known that the core of the electromagnets of existing three-phase low mechanical frequency electromagnetic vibrators (TTEVD) is assembled from electrotechnical steel sheets. The operating principle of the most widespread of such devices is based on the resonance of voltages or currents, devices that work with a series or parallel capacitor connected circuit according to the circuit of the electromagnet [5,6]. When such devices are operating, the stability of the system depends on keeping the specific frequencies of the electrical and mechanical systems at the same or close to each other. It is clear that in the work process, the specific frequency of the mechanical system is variable depending on the mass, while the specific frequency of the electrical system remains practically constant. This causes unstable operation of the electromechanical system of the vibration device. To overcome this deficiency, it is more appropriate to expand the frequency interval of the amplitude-frequency characteristic of the electrical system.

1. Theoretical study of output parameters of three-phase two-stroke electromagnetic vibration device

The improvement and renewal of vibration devices used in various fields of industry requires the study of the movement of their electromagnetic system. For this purpose, let's study the electromagnetic system of the three-phase vibration device, which allows the low mechanical frequency oscillation to get moving (figure 1). In the proposed two-stroke three-phase vibration device, C_A, C_B, C_C are the capacities of the capacitors connected in series to the phases, , r_A, r_B, r_C are

the active resistances of the phases, L_A, L_B, L_C are the specific inductances of the phases, M_{AB}, M_{CA}, M_{BC} are mutual inductances between phases [1,7].

If we write the system of equations of the circuit shown in Figure 1 and show them as a system, we get the following:

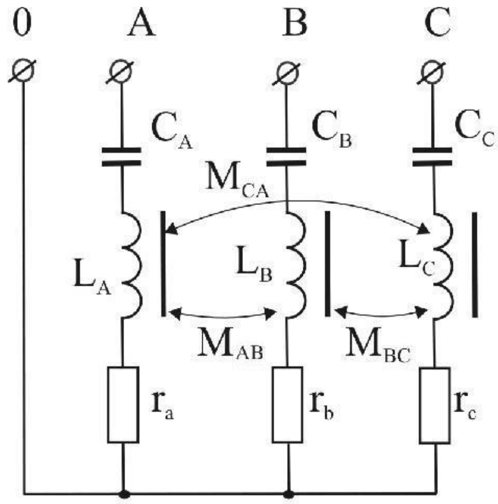

Figure 1. The principle diagram of a three-phase two-stroke vibration device

$$\begin{cases} \dot{I}_A Z_A + jX_{AB}\dot{I}_B + jX_{CA}\dot{I}_C = \dot{U}_A \\ jX_{AB}\dot{I}_A + \dot{I}_B Z_B + jX_{CB}\dot{I}_C = \dot{U}_B \\ \dot{I}_A jX_{CA} + jX_{BC}\dot{I}_B + \dot{I}_C Z_C = \dot{U}_C \end{cases} \tag{1}$$

Here

$$Z_A = r_A + j\left(\omega L_A - \frac{1}{\omega C_A}\right); \quad Z_B = r_B + j\left(\omega L_B - \frac{1}{\omega C_B}\right); \quad Z_C = r_C + j\left(\omega L_C - \frac{1}{\omega C_C}\right);$$

$$X_{BC} = j\omega M_{BC};\ X_{CA} = j\omega M_{CA};\ X_{AB} = j\omega M_{AB}. \tag{2}$$

It should be noted that the number of windings of the phase windings of the device is equal to each other. In addition, the capacities of the capacitors connected in series to the phases are also equal in price. So, $r_A=r_B=r_C=r$; $C_A=C_B=C_C=C$ is accepted.

The specific inductances related to the windings of the phases are obtained from the calculation of the magnetic system of the device and are expressed as follows:

$$L_A = \frac{L_B}{1 + \dfrac{2d}{3n + 3\mu\delta_0}},$$

$$L_B = \frac{W^2 \mu\mu_0 a_1 b_1}{3h + 3\mu\delta_0},$$

$$L_C = \frac{L_B}{1 + \dfrac{2d}{3h + 3\mu\delta_0}}. \tag{3}$$

Here a_1, b_1, h and d - are the width, thickness, height and distance between the rods of the core, respectively.

And the mutual inductive connections between the coils

$$\begin{aligned}
M_{AB} &= \sqrt{L_A \cdot L_B} = \sqrt{\frac{L_B^2}{1 + \dfrac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0}}} = \frac{L_B}{\sqrt{1 + \dfrac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0}}} = \frac{L_B}{1 + \dfrac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0}};\\
M_{CB} &= \frac{L_B}{1 + \dfrac{\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0}};\\
M_{CA} &= \sqrt{L_A \cdot L_C} = \frac{L_B}{\sqrt{\left(1 + \dfrac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta}\right)^2}} = \frac{L_B}{1 + \dfrac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0}}
\end{aligned} \tag{4}$$

is expressed in the form.

According to the given geometric dimensions of the two-stroke three-phase vibration device

$$\frac{2\mathrm{d}}{3\mathrm{h} + 3\mu\delta_0} << 1 \tag{5}$$

considering that in (4) they are $M_{AB}=M_{CB}=M_{CA}$. If we consider inequality (5) in (3) they are $L_A=L_B=L_C=L$.

Considering the above in the expressions of total resistances Z_A, Z_B, Z_C and mutual inductive resistances,

$$\begin{aligned}
Z_A = Z_B = Z_C &= r + j\left(\omega L - \frac{1}{\omega C}\right) = r + jx;\\
\dot{X}_{AB} = \dot{X}_{BC} = \dot{X}_{CA} = \dot{X}_m &= \omega M = \omega\sqrt{L_A L_B} = \omega\sqrt{L_B L_C}
\end{aligned} \tag{6}$$

they are. Thus, (1) system equation as we can write

$$\begin{cases}
\dot{I}_A\left(r + j\dot{X}\right) + j\dot{X}_m\dot{I}_B + j\dot{X}_m\dot{I}_C = \dot{U}_A,\\
\dot{I}_A j\dot{X}_m + \dot{I}_B\left(r + j\dot{X}\right) + \dot{I}_C j\dot{X}_m = \dot{U}_B,\\
\dot{I}_A j\dot{X}_m + \dot{I}_B j\dot{X}_m + \dot{I}_C\left(r + j\dot{X}\right) = \dot{U}_C
\end{cases}. \tag{7}$$

The low mechanical frequency vibration device consists of a two-stroke three-phase electromagnetic core. Such cores belong to the class of ferromagnetic cores, and therefore the main property of the material of such a ferromagnetic core is parametrically very similar to the properties of existing ferromagnets. At the same time, as a result of the theoretical and practical research conducted on the considered two-stroke TTEVD, it was found that if the electrical parameters (U_A, U_B, U_C and I_a, I_b, I_c) in a two-stroke three-phase system form 120° symmetry with each other, then the theoretical-practical operations performed on one of the two tacts can be attributed to both tacts. At the same time, since the winding with the same number of windings is used in all three phases, the inductances of the phase windings will be the same. However, the magnetic losses due to inter-cycle mutual probable periodic current losses are determined by applying the electromagnetic field theory, which is directly proportional to the value of the current. Since the electromagnetic losses on both cycles vary depending on the length of the air gap in the path of the magnetic flux, the air gap in the path of the magnetic flux may differ, even if slightly, in the created two-stroke three-phase vibrating device.

The analysis of the obtained expressions for different phase currents shows that:

- the time variation of the studied quantities in the steady state is non-sinusoidal in nature, which is related to the considerable nonlinearity of the magnetic system;
- at the beginning of the switching process, the nominal value of the current exceeds the nominal value, which is explained by the saturation of the steel of the electromagnets;
- the non-sinusoidal nature of the oscillations has a great influence on the minimum value of the air distance.

Therefore, it is necessary to ensure the linearity of oscillations in order to facilitate the selection of the minimum air distance and to keep its value within reasonable limits. By ensuring the minimum value of the air distance, it is possible to obtain a greater electromagnetic pulling force with minimal energy losses, which is performed by the correct selection of the parameters of the core, anchor and windings of the electromagnet. At the same time, the effect of periodic current loss remains in effect. If we solve the cyclic currents generated in the proposed two-stroke TTEVD core using the course of the theory of electromagnetic fields, the quantities L and M included in expressions (3) and (4) are obtained in complex form:

$$L = L_a - jL_r; \quad M = M_a - jM_r \, . \tag{8}$$

as it is written. Considering these statements in (2):

$$\begin{aligned} j\,x &= j\left[\omega\left(L_a - jL_r\right) - \frac{1}{\omega c}\right] = (\omega)L_r + j\left(\omega L_a - \frac{1}{\omega c}\right), \\ jx_m &= j\left[\omega\left(M_a j - M_r\right)\right] = \omega M_r + j\omega M_a \end{aligned} \tag{9}$$

can. If we consider the expression (9) in (5), the following expression is obtained for the work performed by the three-phase vibration device in the symmetrical mode:

$$\begin{cases} I_A\left[r_A+\omega L_r+j\left(\omega L_a-\dfrac{1}{\omega c}\right)\right]e^{-j0}+\left(\omega M_r+j\omega M_a\right)I_A e^{-j120^0}+ \\ +\left(\omega M_r+j\omega M_a\right)I_A e^{-j240}=\dot{U}_A, \\ I_A(\omega M_r+j\omega M_a)e^{j0}+I_A(\omega M_r+j\omega M_a)e^{-j120^0}+ \\ +(\omega M_r+j\omega M_a)I_A e^{-j240}=\dot{U}_B, \\ I_A(\omega M_r+j\omega M_a)e^{j0}+I_A\left(\omega M_r+j\omega M_a\right)e^{-j120^0}+ \\ +\left(\omega M_r+j\omega M_a\right)I_A e^{-j240^0}=\dot{U}_C \end{cases} \tag{10}$$

Each equation of system (10) is an independent equation. If the complex form of the phase voltages in these equations is expressed by their effective values, then from the first equation of (10)

$$I_A=\frac{a^3U}{r_A+\omega L_r+j\left(\omega L_a-\dfrac{1}{\omega c_A}\right)+\left(\omega M_r+j\omega M_a\right)e^{-j120^0}+\left(\omega M_r+j\omega M_a\right)e^{-j240^0}} \tag{11}$$

from the second equation

$$I_A=\frac{a^2U}{r_A+\omega L_r+j\left(\omega L_a-\dfrac{1}{\omega c_A}\right)+\left(\omega M_r+j\omega M_a\right)e^{-j120^0}+\left(\omega M_r+j\omega M_a\right)e^{-j240^0}} \tag{12}$$

from the third equation

$$I_A=\frac{a\,U}{r_A+\omega L_r+j\left(\omega L_a-\dfrac{1}{\omega c_A}\right)+\left(\omega M_r+j\omega M_a\right)e^{-j120^0}+\left(\omega M_r+j\omega M_a\right)e^{-j240^0}} \tag{13}$$

is taken. Here

$$a^3=1;\ a^2=-\frac{1}{2}-j\frac{\sqrt{3}}{2};\ a=-\frac{1}{2}+j\frac{\sqrt{3}}{2}. \tag{14}$$

Thus, the denominators of the fractions in the received expressions (11), (12) and (13) are the same, and it is enough to study the denominator of one of them to obtain research results for the resonance mode of each phase. Let us assume that the frequency of the supply voltage is ω and the resonant frequency of the circuit is ω_0. Accordingly, voltage resonance occurs in a given series circuit and the specific frequency of this circuit

$$\omega_0=\frac{1}{C\cdot\left(L_a+M_a\right)} \tag{15}$$

is written as If we consider this in the expression of the total resistance of the denominator of expression (11), we get:

$$Z = r_a + \omega_0 (L_r - M_r) + j\omega_0 (L_a - M_a) \left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right] \qquad (16)$$

We write from here:

$$\frac{Z}{r_A + \omega_0 (L_r - M_r)} = 1 + j \frac{\omega_0 (L_a - M_a)}{r_A + \omega_0 (L_r - M_r)} \left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right] \qquad (17)$$

Here, $\omega_0 (L_r - M_r)$ is the active resistance transferred from the magnetic circuit to the loop and has the same character as the resistance r_A. If we make some changes in the last expression and go to the module of the expression, we write:

$$\frac{Z}{r_A} \frac{1}{1+Q_r} = \sqrt{1 + \frac{Q_a^2}{(1+Q_r)^2} \left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right]^2} \qquad (18)$$

If we make a transformation in this expression, we write as follows:

$$\frac{Z}{r_A} = \sqrt{(1+Q_r)^2 + Q_a^2 \left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right]^2} \qquad (19)$$

Based on the obtained expression (19), the frequency characteristic of the resistance can be established. In this case, the ratio of frequencies $\frac{\omega}{\omega_0}$ is accepted as an argument. The term Q_r in expression (19) was the coefficient related to the current losses is defined as

$$Q_r = \frac{\omega_0 (L_r - M_r)}{r_A}. \qquad (20)$$

The quantity Q_a depends on the difference between the active parts of specific inductance and mutual inductance and is determined by the expression

$$Q_a = \frac{\omega_0 (L_a - M_a)}{r_A} \qquad (21)$$

This coefficient is called the quality coefficient of one phase of the three-phase system.

2. Modeling results of the frequency characteristics of the output parameters of the TTEVD

The frequency-dependent characteristic of the ratio of the total resistance to the active resistance of the phase loop is given in figure 2. The characteristic reflects the dependence of the ratio of total resistance (impedance) Z to the active resistance r_A of the phase loop on the frequency ratio $\frac{\omega}{\omega_0}$. Expression (19) was used to establish these characteristics. Curve 1 shown in Figure 2 is at the value of $Q_a = 4$ and $Q_r = 3$; 2 curve $Q_a = 10$, $Q_r = 3$; 3 curve $Q_a = 100$, $Q_r = 3$; Curve 4 is constructed according to the values of $Q_a = 1000$ and $Q_r = 3$.

From the obtained characteristics, it is clear that when the coefficient of quality Q_a is higher, the steepness of the characteristic is obtained more than the curves of $Q_a = 10$ and $Q_a = 100$. Due to this, the normal operation of the three-phase vibrator is ensured in the entire frequency range. However, the normal operating mode assumed at values of $Q_a = 10$, 100 and above is violated [7].

If we denote the currents flowing through the circuit of each phase by I_{AO} corresponding to the resonance operating mode and $\dot{I}_A$ corresponding to the current value of the frequency, we get:

$$\frac{I_A}{I_{AO}} = \frac{1}{\sqrt{(1+Q_r)^2 + Q_a^2\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2}} \tag{22}$$

Based on the expression (22), the dependence of the modulus of the phase currents on the ratio $\frac{\omega}{\omega_0}$ is established, and these are also shown in figure 3. It can be seen from Figure 3 that when the quality factor changes in the range of 4÷100, the parallelism of the resonance curve to the $\frac{\omega}{\omega_0}$ axis is practically maintained in the specified frequency range of the proposed device. This is due to the presence of periodic currents generated in the core of this three-phase vibrating device. It is clear from Figure 3 that the rate of frequency-dependent reduction of the amplitude decreases as Q_a decreases.

In Figure 4, the $\frac{I_A}{I_{AO}} = F\left(\frac{\omega}{\omega_0}\right)$ characteristics are plotted at different values of Q_r, with $Q_a = 100$ remaining constant. It can be seen from the characteristics obtained here that the steepness of the resonance curve decreases due to the increase in the cyclic current losses generated in the core of the vibrator. In the figure, curve 1 is constructed at the value of $Q_r = 1$, curve 2 at the value of $Q_r = 3$ and curve 4 at the value of $Q_r = 4$.

The same characteristic curves are shown for the frequency dependence of the relative resistance corresponding to the resonance mode (figure 5). Here, both characteristics are set according to the values of $Q_r = 1$ and $Q_r = 4$.

Figure 3 shows the frequency-dependent characteristics of the phase shift angle at different quality factor and constant Q_r. The changing nature of the curves in this figure repeats the changing nature of the curves in figure 4 and figure 5.

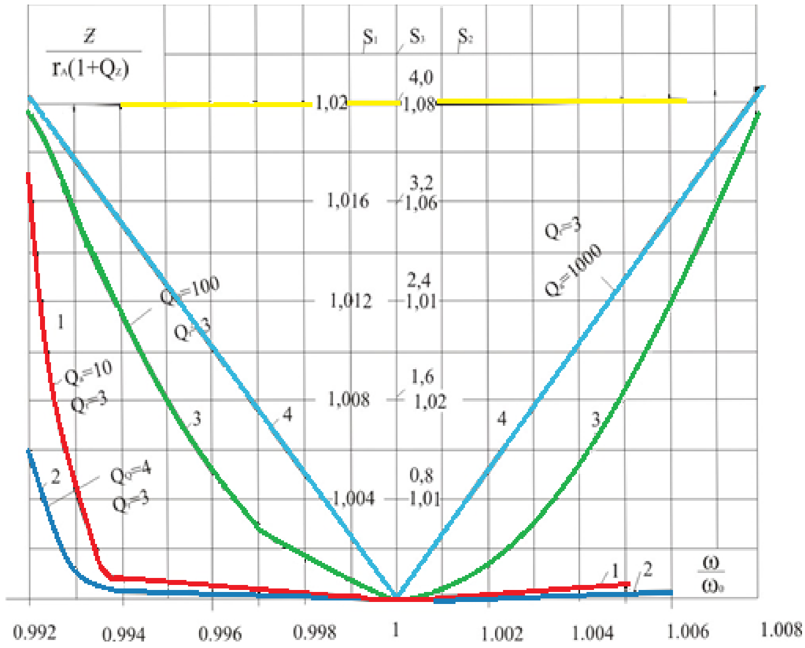

Figure 2. $\dfrac{Z}{r_A(1+Q_r)}=F(\dfrac{\omega}{\omega_0})$ characteristics

S_1, S_2, S_3 - are scales.

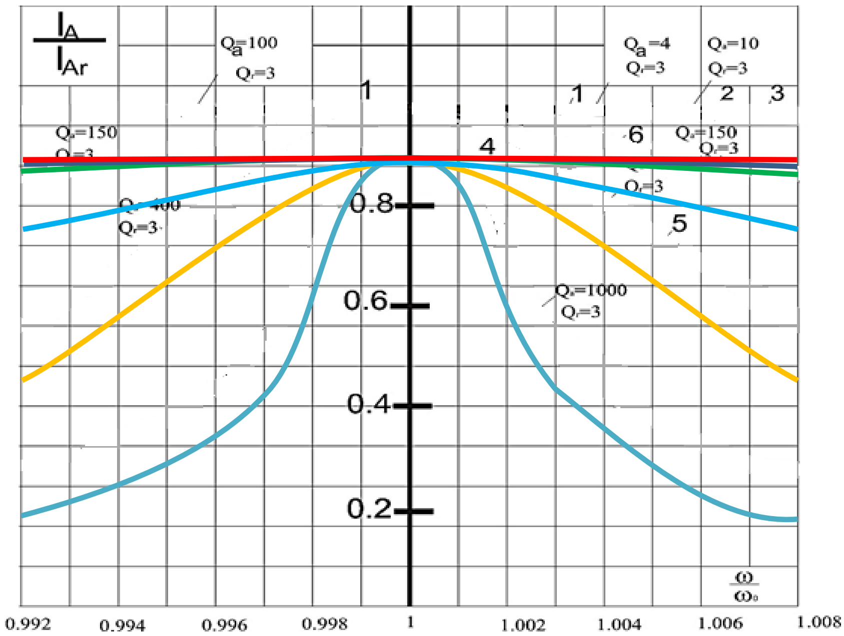

Figure 3. $\dfrac{I_A}{I_{Ar}}=F\left(\dfrac{\omega}{\omega_0}\right)$ characteristics

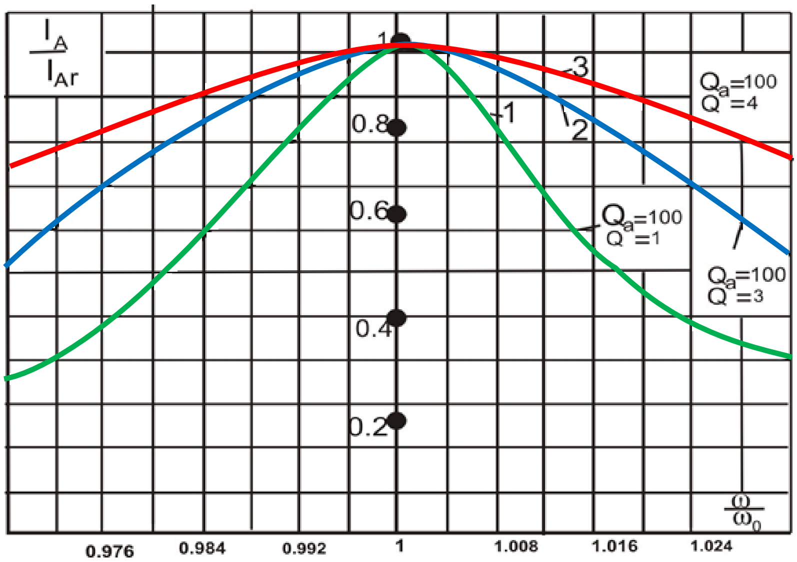

Figure 4. $\dfrac{I_A}{I_{AO}} = F\left(\dfrac{\omega}{\omega_0}\right)$ characteristics

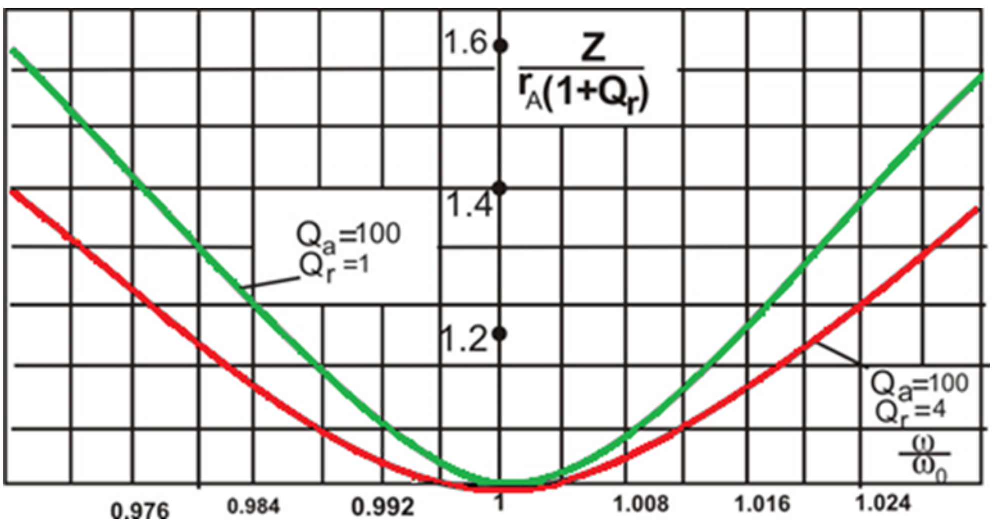

Figure 5. Frequency-dependent characteristics of relative resistance

Thus, the obtained last expressions allow to determine the dependence of the voltage applied to the input of the circuit on the specific inductance and the frequency change. It is known from the course of theoretical foundations of electrical engineering that during resonance, the circuit consists of only active (R) resistance, as the inductive resistance is compensated by the capacitive resistance. This frequency obtained in vibration devices is close to the specific frequency of the mechanical system and is approximately three times smaller than the frequency of the feeding voltage. On the other hand, when $\omega > \omega_0$, the frequency change β is positive, and when $\omega < \omega_0$, it is negative. When ω =0, β =0 at $\beta = -1$ resonance frequency.

CONCLUSIONS

1. The study of the electromagnetic system of the low mechanical frequency TTEVD, according to the quality factor corresponding to the resonance mode of its electric circuit, the expressions reflecting the complete electrical resistance of the phases, taking into account the current losses in the magnetic circuit, and based on these expressions, the characterization of the ratio of the current values of the phase currents to its resonance current is assigned. From the obtained characteristics, it was found that the steepness of the resonance curve of the system decreases as the value of the quality factor decreases. The value of the coefficient of quality Q_a =4; When 10 and 100, the characteristics obtained in the intended low frequency interval (below 20 Hs) are practically parallel to the ω/ω_0 line, which makes it reasonable to use P-10 brand steel in the preparation of the core.

2. A mathematical model was obtained with the help of the working parameters and output characteristics of the device by designing the equivalent electrical circuit of the low mechanical frequency three-phase TTEVD. The theoretically obtained characteristics and report results, which correctly and comprehensively reflect the processes taking place in the three-phase vibrator, have been confirmed experimentally.

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MODELS OF ENERGY SYSTEM ELEMENTS IN PHASE COORDINATES FOR THE STUDY OF NON-SYMMETRICAL STEADY AND TRANSITION REGIMES

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Annotation. One of the main issues is the construction of mathematical models of its elements and three-phase replacement schemes in order to study the non-symmetric steady-state and transition modes of modern energy systems in phase coordinates. Therefore, in the work under review, the replacement scheme and mathematical models of the main elements for the calculation of the non-symmetric steady-state and transition processes of the energy system are given.

Keywords: energy system, phase-coordinates, three-phase alternating scheme, non-symmetric steady state, transition processes.

QEYRİ-SİMMETRİK QƏRARLAŞMIŞ VƏ KEÇİD REJİMLƏRİNİN TƏDQİQİ ÜÇÜN ENERJİSISTEMİN ELEMENTLƏRİNİN FAZA KOORDİNATLARINDA MODELLƏRİ

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Annotasiya. Müasir enerjisistemlərin qeyri-simmetrik qərarlaşmış və keçıd rejimlərini faza koordinatlarında tədqiq etmək üçün onun elementlərinin riyazi modellərinin və üçfazalı əvəz sxemlərinin qurulması əsas məsələlərdən biridir. Buna görə də baxılan işdə enerjisistemin qeyri-simmetrik qərarlaşmış və keçid proseslərinin hesablanması üçün əsas elementlərin əvəz sxemi və riyazi modelləri verilmişdir.

Açar sözlər: enerjisistem, faza kordinatları, üçfazalı əvəz sxemi, qeyri-simmetrik qərarlaşmış rejim, keçid prosesləri.

МОДЕЛИ ЭЛЕМЕНТОВ ЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ В ФАЗОВЫХ КООРДИНАТАХ ДЛЯ ИССЛЕДОВАНИЕ НЕСИММЕТРИЧНЫХ УСТАНОВИВШИХСЯ И ПЕРЕХОДНЫХ РЕЖИМОВ

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Аннотация. Одним из основных вопросов современных энергетических систем является построение математических моделей ее элементов и трехфазной схемы замещения с целью исследования несимметричных установившихся и переходных режимов в фазовых координатах. Поэтому в ррассмотренной работе приведены схема замещения и математические модели основных элементов для расчета несимметричных установившихся и переходных процессов энергосистемы.

Ключевые слова: энергетическая система, фазовые координаты, трехфазная схема замещения, несимметричный установившийся режим, переходные процессы.

INTRODUCTION

Currently, methods and programs for calculating steady-state modes (SSM) and transient processes in complex electric power systems (EES) are built on the basis of the direct sequence substitution scheme. In order to model transition processes in non-symmetrical short-circuit and incomplete phase modes, instead of asymmetry, the option of connecting a shunt or an additional resistance was used. In order to determine the additional resistance, it is required to carry out additional reports of the phase and line voltage at all branch and node points, taking into account the reverse and zero-sequence electrical quantities in the asymmetric mode, and also at the generator and load nodes of the circuit in complex networks during the switching process. Therefore, it becomes difficult to solve the problem with traditional methods and programs, and it is impossible to solve the problem in complex asymmetric modes, when transposition is rejected, when the parameters of the line and other elements of the system differ in phase, and also when the three-phase transformers feeding distribution substations are connected with a special scheme.

Taking these into account, it is considered the best method to determine the electrical quantities of the circuit in the phase coordinates in steady-state and transient modes [1].

The advantage of the *a*, *b*, *c* coordinate system over other systems is that all the mode quantities correspond to real values and recalculation of the results is not required to obtain the phase quantities.

The solution of the given problem in phase coordinates is universal to a great extent, as various types of short-circuits and phase breaks are easily performed, and the simplicity of the algorithm allows it to be used in modern high-performance computers. In this case, the main difficulty is to obtain a three-phase replacement scheme for ES elements in non-symmetrical quasi-steady and transient modes. Therefore, in the considered work, the replacement scheme and mathematical models of the main elements of ES for the calculation of non-symmetric SSM are given [1-12].

I. MATHEMATICAL MODELS AND SUBSTITUTION SCHEMES IN PHASE COORDINATES FOR THE CALCULATION OF NON-SYMMETRIC SSM AND TRANSITION MODES OF SYSTEM ELEMENTS

Mathematical models of the elements of the system and the solution of the problem for the description of the replacement schemes in phase coordinates consists of two stages. At the first stage, the calculation of the non-symmetric settled mode in the phase coordinates is carried out [7], but here it is taken into account that the replacement scheme in the pre-crash mode differs noticeably from the scheme of the unilinear mode for the reasons we mentioned above. In the second stage, in the adjustable multi-machine ES, the integration of the transition processes in the phase coordinates with the reporting program is performed, taking into account the full Park-Gorev equations. In the work under review, the equations for the stator loop are formulated using the *a*, *b*, *c* coordinate system, and the rotor quantities are formulated using the *d*, *q*, 0 system. The periodic coefficients in the equations of the synchronous machine are calculated as the angle between the stator and rotor axes in each interval of the mathematical solution of the equations. It should be

noted that since the periodic coefficients in those equations are expressed by $\sin\gamma$ and $\cos\gamma$, their calculation does not cause any difficulties.

In the first stage, the method of calculating the phase coordinates of the three-phase electric system was considered. Each three-phase element is illustrated with a corresponding replacement diagram. In this case, the operation of power transformers and autotransformers in complex transformation ratio for different branching and voltage regulation is taken into account. A matrix of nodal equations is constructed for other elements of the system. Based on it, a dialogue complex is created that allows to combine the results of the report not only for relay protection and automation, but for a more complex issue, i.e. for mode symmetrization, and also with the calculation program of electromechanical processes (calculation of short-circuit shunt) in phase coordinates. Below is a description of the various three-phase elements of the system in nodal equations. Hereafter, all quantities are expressed in relative units (p.u.).

1.1. A model of a synchronous machine

If the neutral of the generator is grounded through a conductor as shown in figure 1 and considering $\dot{I}_N = \dot{I}_4 + \dot{I}_5 + \dot{I}_6 + \dot{Y}_{N0}\dot{U}_N$ [7] we write:

$$\begin{vmatrix} \dot{Y}_{11} & \dot{Y}_{12} & \dot{Y}_{13} & -\dot{Y}_1 & -\dot{Y}_0 \\ \dot{Y}_{21} & \dot{Y}_{22} & \dot{Y}_{23} & -a^2\dot{Y}_1 & -\dot{Y}_0 \\ \dot{Y}_{31} & \dot{Y}_{32} & \dot{Y}_{33} & -a\dot{Y}_1 & -\dot{Y}_0 \\ -\dot{Y}_1 & -a\dot{Y}_1 & -a^2\dot{Y}_1 & 3\dot{Y}_1 & 0 \\ -\dot{Y}_0 & -\dot{Y}_0 & -\dot{Y}_0 & 0 & 3\dot{Y}_0+\dot{Y}_{N0} \end{vmatrix} \begin{vmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ E_a \\ U_N \end{vmatrix} = \begin{vmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \dot{I}_3 \\ \dfrac{\Sigma\dot{S}}{\dot{E}_a} + \dfrac{\dot{Y}_{N0}|\dot{U}|}{\dot{E}_a} \\ 0 \end{vmatrix}, \qquad (1)$$

here $a = 1\angle 120^0 = e^{j2\pi/3}$; $\dot{Y}_1$, $\dot{Y}_2$, $\dot{Y}_0$ – forward, reverse and zero sequence conductors.

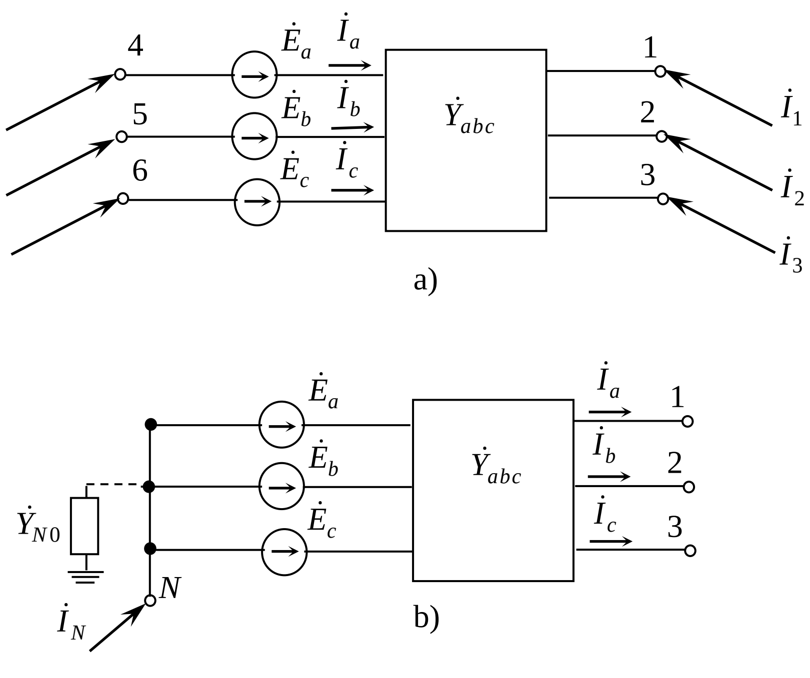

Figure 1. General (a) and generator (b) three-phase replacement schemes of the system in case of $\dot{Y}_1 = \dot{Y}_2$

The matrix expression (1) includes the total power $\Sigma\dot{S} = \dot{S}_a + \dot{S}_в + \dot{S}_c$ of the synchronous generator or induction motor. In the latter case, $\Sigma\dot{S}$ is taken with a minus sign. $\dot{I}_1$, $\dot{I}_2$ and $\dot{I}_3$ currents are the phase currents at the output of the machine. The in expression (1) the E_a emf of phase A, for which the calculation is performed, is taken as the main parameter.

When carrying out calculations in a complex network, one node is taken as a balancing node. Then expression (1) for such a node will take the following form:

$$\begin{vmatrix} \dot{Y}_{11} & \dot{Y}_{12} & \dot{Y}_{13} & -\dot{Y}_0 \\ \dot{Y}_{21} & \dot{Y}_{22} & \dot{Y}_{23} & -\dot{Y}_0 \\ \dot{Y}_{31} & \dot{Y}_{32} & \dot{Y}_{33} & -\dot{Y}_0 \\ -\dot{Y}_0 & -\dot{Y}_0 & -\dot{Y}_0 & 3\dot{Y}_0 + \dot{Y}_{N0} \end{vmatrix} \begin{vmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ 0 \end{vmatrix} = \begin{vmatrix} \dot{S}_1/\dot{U}_1 + & \dot{Y}_1 E_a^{бал} \\ \dot{S}_2/\dot{U}_2 & a^2\dot{Y}_1 E_a^{бал} \\ \dot{S}_3/\dot{U}_3 & a^2\dot{Y}_1 E_a^{бал} \\ 0 & \end{vmatrix}. \tag{2}$$

For a generator unit specified as $P_Г | \dot{U} |$, the total active power is determined taking into account $\dot{E}_a$. Applying (2), you can obtain the values of apparent and reactive:

$$\Sigma\dot{S} = E_a\dot{Y}(-\dot{U}_1 - a\dot{U}_2 - a^2U_3) + 3\dot{Y}_1 |\ \dot{E}_a\ |^2 - \dot{Y}_{N0} |\ U_N\ |^2,$$

$$Q\ = -I_m\left\{\dot{E}_a\dot{Y}_1(-\dot{U}_1 - a\dot{U}_2 - a^2U_3) + 3\dot{Y}_1 |\ \dot{E}_a\ |^2 - \dot{Y}_{N0} |\ U_N\ |^2\right\}$$

In this case, the matrix expression (1) can be used as a model of a synchronous machine in quasi-deterministic non-symmetrical and short-circuit reporting.

1.2. Model of power transformers

To obtain the model of different transformers in phase coordinates, the substitution scheme shown in figure 2,a is used without taking into account the magnetization resistance of an ideal single-phase two-winding transformer. According to the replacement scheme of the given ideal transformer, the replacement scheme of the single-phase two-winding transformer given in figure 2,b can be obtained. When the nodes k and q are grounded, the replacement circuit turns into a P-shaped circuit (Fig. 2,c).

To adjust the voltage of power transformers (autotransformers) in a complex electrical system, it is convenient to calculate the operating modes in its various branches, to recalculate the branching resistance of the transformer without changing the resistances of other elements. It should be taken into account that recalculation of the resistance in many elements of the system is required when branching is connected in the replacement circuit, where the resistances are brought to one step of the voltage. In this case, the transformation coefficients of the transformers are recalculated to find the true value of the current and voltage. Therefore, it is more appropriate to maintain the transformer connection by taking into account the change of branching in the replacement circuits.

Figure 2,d shows a generalized replacement scheme, taking into account the change of branching in the first (α) and second (β) windings of a two-winding single-phase transformer. In

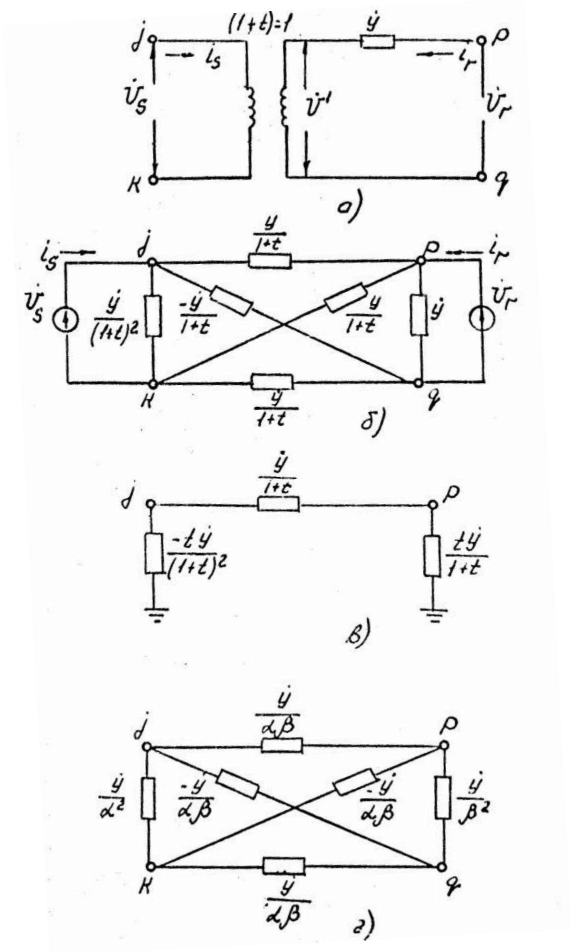

Figure 2. Two-winding transformer and its replacement circuits:a – two winding transformer; b - X-shaped substitution scheme, considering the transformation factor as (1+t):1; c – P-shaped substitution scheme; d - X-shaped substitution scheme, taking into account branching in the first (α) and second (β) circuits

this case $\dot\alpha = 1 + t_\alpha$, $\beta = 1 + t_\beta$ here $t_{\dot\alpha}$ and t_β shows the change in the number of windings of the first and second windings. For example, if the transformation factor is 1.025:1 in p.u., then $t_{\dot\alpha}$=0,025, t_β=0. It should be noted that $t_{\dot\alpha}$ and t_β can be negative and positive.

In accordance with the generalized replacement scheme of a single-phase two-winding transformer, the phase diagrams for different types of transformers and their conductivities were obtained taking into account the change of their branching [2].

In this case, according to the obtained diagrams, the transformers are shown in the form of $|\dot Y_T|$ a matrix of node conductors in phase.

1.3. Power transmission line model

The mathematical model of the electric transmission line (ETL) in phase coordinates is constructed according to the line model for a single-line circuit. For an example, we will look at phase A, which is connected to phase B of a three-phase ETL (Fig. 3, a and b). For the case we are looking at, we can write the expression in the form of a matrix below:

$$\begin{vmatrix} \dot{U}_a \\ U_в \end{vmatrix} = \begin{vmatrix} \dot{Y}_{ав} + & \frac{1}{2}\dot{Y}'_{ав} & -\dot{Y}_{ав} \\ -\dot{Y}_{ав} & \dot{Y}_{ав} + & \frac{1}{2}\dot{Y}'_{ав} \end{vmatrix} \begin{vmatrix} I_a \\ I_в \end{vmatrix}, \tag{3}$$

here $\dot{Y}_{ав} = Z_{ав}^{-1}$ – it was mutual conductivity between phases *a* and *b*; $\dot{Y}'_{ав}$ – value of the conductance of the shunt connected to ground; $\dot{U}_a, \dot{U}_в$ və $\dot{I}_a, \dot{I}_в$ – are the node voltages and currents, respectively.

(3) for the three-line model, taking into account the transverse interconnections and conductances to ground (shunt) of the ETL, can be written according to Fig. 3, c and d:

$$\begin{vmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \dot{I}_3 \\ \dot{I}_4 \\ \dot{I}_5 \\ \dot{I}_6 \end{vmatrix} = \begin{vmatrix} \dot{Y}_{авв} + \frac{1}{2}\dot{Y}_{shunt} & -\dot{Y}_{авв} \\ -\dot{Y}_{авв} & \dot{Y}_{авв} + \frac{1}{2}Y_{shunt} \end{vmatrix} \begin{vmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ \dot{U}_4 \\ \dot{U}_5 \\ \dot{U}_6 \end{vmatrix}, \tag{4}$$

here $\dot{Y}_{авс} = Z_{авс}^{-1}$

$$\dot{Y}_{shunt} = \begin{vmatrix} \dot{Y}'_{a\circ} & \dot{Y}'_{ав} & \dot{Y}'_{ac} \\ \dot{Y}'_{вa} & \dot{Y}'_{в\circ} & \dot{Y}'_{вc} \\ \dot{Y}'_{ca} & \dot{Y}'_{cв} & \dot{Y}'_{c\circ} \end{vmatrix}. \quad Z_{авс} = \begin{vmatrix} \dot{Z}_{aa} & \dot{Z}_{ав} & \dot{Z}_{ac} \\ \dot{Z}_{вa} & \dot{Z}_{вв} & \dot{Z}_{вc} \\ \dot{Z}_{ca} & \dot{Z}_{cн} & \dot{Z}_{cc} \end{vmatrix}. \tag{5}$$

In this case, comparing the one-line diagram of ETL with the three-line diagram, it can be seen that each element in the three-line consists of a 3x3 matrix.

$\dot{Z}_{авс}$ (or $\dot{Y}_{авс}$) resistance matrix (5) can be determined according to the basic parameters in a suitable straight way or with the help of a transformation matrix including pre-calculated symmetric complexes ($\dot{Z}_o$, $\dot{Z}_1$, $\dot{Z}_2$). If the matrix of symmetric complexities is defined as a diagonal matrix $\dot{Z}_{012}$, then we can write:

$$|\ \dot{Z}_{авс}\ | = \frac{1}{3}|\ \dot{T}\ ||\ \dot{Z}_{012}\ ||\ \dot{T}\ |^{\Pi}, \tag{6}$$

where $|\ T\ |^{\Pi}$ the transformation matrix is determined:

$$|\ \dot{T}\ |^{\Pi} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix}.$$

Here, in the expression (6), it is taken into account that the straight and reverse sequence resistances (om/кm, f=50 Hs) of the three-phase single-cycle ETL are the same. Therefore, the matrix $Z_{авс}$ determined according to expression (6) is symmetric.

Taking into account the above, expression (5) can be written as follows:

$$\dot{Z}_{авс} = \begin{vmatrix} Z_{aa} & Z_{ав} & Z_{ac} \\ Z_{ав} & Z_{вв} & Z_{вс} \\ Z_{ac} & Z_{вс} & Z_{cc} \end{vmatrix}. \tag{7}$$

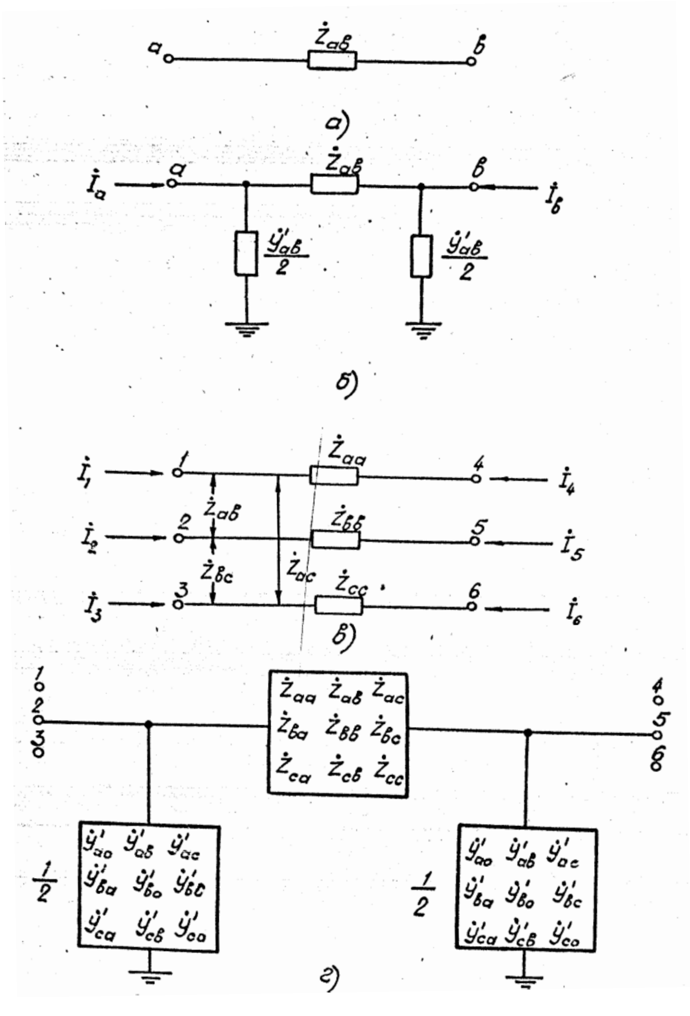

Figure 3. Scheme of three-phase ETL

a- single line diagram of three-phase ETL; b- replacement scheme of ETL, taking into account the conductivity to ground; c- replacement scheme of the ETL, taking into account its transverse connection; d- replacement scheme of the ETL, taking into account the transverse connection and conductances (shunts).

In other words, the number of (N) elements forming the matrix (7) is 6. In order to determine the elements of the resistance (conductance) matrix for three-phase circuits, including single-line circuits, the following expression is used:

$$N = \frac{1}{2}(n + n^2)$$

here, n – is the total number of wires. For example, for a single-phase line $N=1$, and for a three-phase line N=3. If the fourth wire of the three-phase ETL is also taken into account (figure 4), then N=10. Therefore, the symmetric matrix $\dot{Z}_{авс}$ will have the following form:

$$\dot{Z}_{авсз} = \begin{vmatrix} Z_{aa} & Z_{ав} & Z_{ac} & Z_{аз} \\ Z_{ав} & Z_{вв} & Z_{вс} & Z_{вз} \\ Z_{ac} & Z_{вс} & Z_{cc} & Z_{сз} \\ Z_{аз} & Z_{вз} & Z_{сз} & Z_{зз} \end{vmatrix} \qquad (8)$$

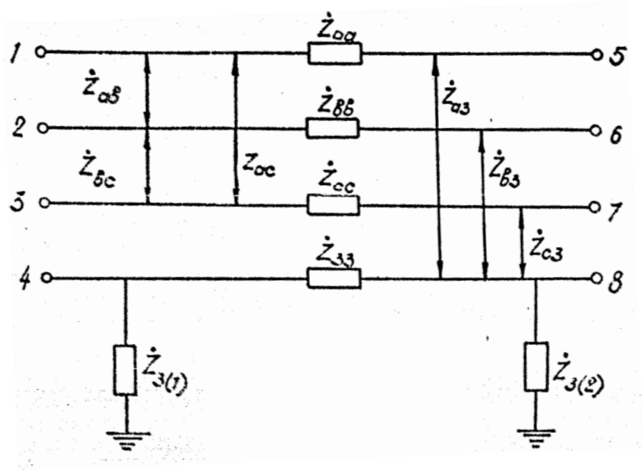

Figure 4. Four-wire scheme of three-phase ETL

Considering expression (8), the knot matrix expression takes the form below:

$$\begin{vmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \dot{I}_3 \\ \dot{I}_4 \\ \dot{I}_5 \\ \dot{I}_6 \\ \dot{I}_7 \\ \dot{I}_8 \end{vmatrix} = \begin{vmatrix} \dot{Y}_{авсз} + \frac{1}{2}\dot{Y}_{shunt} + \dot{Y}_{зi} & -\dot{Y}_{авсз} \\ -\dot{Y}_{авсз} & \dot{Y}_{авсз} + \frac{1}{2}\dot{Y}_{shunt} + \dot{Y}_{зi} \end{vmatrix} \begin{vmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ \dot{U}_4 \\ \dot{U}_5 \\ \dot{U}_6 \\ \dot{U}_7 \\ \dot{U}_8 \end{vmatrix}, \qquad (9)$$

here, $\dot{Y}_{авсз} = (\dot{Z}_{авсз})^{-1}$

$$\dot{Y}_{зi} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/\dot{Z}_{зi} \end{vmatrix}, \ i = 1,2$$

1.4. Load model

In the reports, the unsymmetrical load can be given according to the value of the full power on the phases. In this case, if the adjustment ranges of the transformers are defined clearly enough, then they can be given in the form of $\dot{S}_H = P_H + jQ_H = const$ in their non-symmetric reports. It should be noted that the value of voltage is not the same in case of asymmetrical distribution of loads according to phases. Therefore, in the calculation of non-symmetrical electrical SSM, the load $\dot{Y}_{нш} = \text{const}$ cannot be considered as a shunt with constant conductance. The value of $\dot{Y}_{нш}$ is determined separately for each phase. In this setting, mode reporting can only be done with iteration methods.

II. MODELING RESULTS FOR SYMMETRIC MODES IN PHASE COORDINATES

Table 1

Parameters of the generator

Type of machine		salient pole
The voltage		6 kV
Power		1290 kVA
Speed of rotation		300 cycle/min.
Number of poles		20
The voltage of the exciter		80 V
Resistances	X_d	0,957 p.u.
	X'_d	0,345 p.u.
	X''_d	0,193 p.u.
	X_2	0,196 p.u.
	X'_2	0,282 p.u.
	X_0	0,0573 p.u.
Time constants	T'_d	1,03 s
	T''_d	0,052 s
	T_a	0,0816 s
Parameters of the exciter		
	X_{lf}	0,17 p.u.
	X_{al}	0,15 p.u.
	R_f	0,2 Om, 75°

Calculation experiments were carried out for the synchronous machine test sample scheme [15] working in the system for the purpose of visual representation of the developed methodology for the description of the energy system elements in phase coordinates and the software's functionality. Initially, the symmetric mode was considered. All the necessary data of the generator for the studied system are given in table 1.

The report results in the phase coordinates for the three-phase short-circuit at the generator outputs are given in table 2 in the mode with power flows, and in table 3 in the case of power flows. The obtained table results and the experimental curves of the transition process (Fig. 5) completely coincide, which confirms the adequacy of the models of system elements presented in phase coordinates.

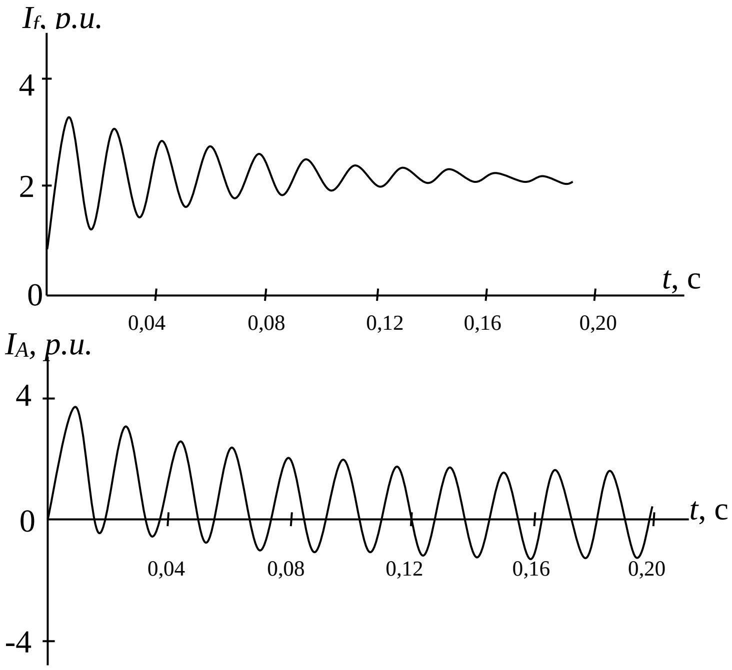

Figure 5. Variation curves of the induced current (a) and the current of phase A (b) during a three-phase short circuit

Table 2

Results of calculation of SSM in phase coordinates (simmetric)

Node no	Node type	$\lvert\dot{U}\rvert$ (p.u)	Angle (deg)	P_g (MW)	Q_g (MVAR)	P_l (MW)	Q_l (MVAR)
1	3	1,056	-1,527	0,000	0,000	0,000	0,000
2	3	1,056	-121,656	0,000	0,000	0,000	0,000
3	3	1,056	118,479	0,000	0,000	0,000	0,000
4	3	1,054	-1,540	0,000	0,000	0,000	0,000
5	3	1,054	-121,575	0,000	0,000	0,000	0,000
6	3	1,054	116,490	0,000	0,000	0,000	0,000
7	3	1,055	-2,431	0,000	0,000	0,000	0,000
8	3	1,055	-122,460	0,000	0,000	0,000	0,000
9	3	1,055	117,608	0,000	0,000	0,000	0,000
10	3	1,048	87,473	0,000	0,000	8,333	5,000
11	3	1,048	-32,453	0,000	0,000	8,333	5,000
12	3	1,048	-152,507	0,000	0,000	8,333	5,000
13	3	1,043	87,153	0,000	0,000	10,000	6,333
14	3	1,043	-32,757	0,000	0,000	10,000	6,333
15	3	1,043	-152,809	0,000	0,000	10,000	6,333
16	3	1,045	87,183	0,000	0,000	11,670	7,333
17	3	1,045	-32,741	0,000	0,000	11,670	7,333
18	3	1,045	-152,736	0,000	0,000	11,670	7,333
19	3	1,043	87,099	0,000	0,000	10,000	6,333
20	3	1,043	-32,819	0,000	0,000	10,000	6,333
21	3	1,043	-152,861	0,000	0,000	10,000	6,333
22	3	1,043	87,086	0,000	0,000	13,333	8,333
23	3	1,043	-32,830	0,000	0,000	13,333	8,333
24	3	1,043	-152,872	0,000	0,000	13,333	8,333
25	1	1,070	0,000	32,373	16,230	0,000	0,000
26	1	1,070	-120,072	32,306	15,976	0,000	0,000
27	1	1,070	120,072	32,497	16,081	0,000	0,000
28	5	0,000	0,000	0,000	0,000	0,000	0,000
29	4	1,070	0,185	19,985	10,151	0,000	0,000
30	4	1,070	-119,839	20,105	10,292	0,000	0,000
31	4	1,070	120,209	19,912	10,329	0,000	0,000

32	5	0,000	0,000	0,000	0,000	0,000	0,000
33	3	1,057	-2,385	0,000	0,000	6,000	2,333
34	3	1,057	-122,414	0,000	0,000	6,000	2,333
35	3	1,057	117,649	0,000	0,000	6,000	2, 333
36	4	1,070	-1,522	10,047	8,272	0,000	0,000
37	4	1,070	-121,546	10,075	8,292	0,000	0,000
38	4	1,070	118,502	9,880	8,428	0,000	0,000
39	5	0,000	0,000	0,000	0,000	0,000	0,000
40	3	0,521	-93,090	0,000	0,000	0,000	0,000
41	3	0,855	83,150	0,000	0,000	0,000	0,000
42	3	0,836	-5,011	0,000	0,000	0,000	0,000
43	3	0,297	-76,996	0,000	0,000	0,000	0,000
44	3	0,004	-175,166	0,000	0,000	0,000	0,000
45	3	0,602	67,101	0,000	0,000	0,000	0,000
46	3	0,602	-32,817	0,000	0,000	0,000	0,000
47	3	0,602	-152,660	0,000	0,000	0,000	0,000
48	3	1,043	-122,888	0,000	0,000	0,000	0,000
49	3	1,043	117,158	0,000	0,000	0,000	0,000
50	3	1,043	-2,545	0,000	0,000	0,000	0,000

Table 3

Reporting results of SSM in phase coordinates (symmetrical mode, power flows)

Start of node	End of node	P (MW)	Q (MVAR)	Start of node	End of node	P (MW)	Q (MVAR)
1	25	-32,373	-15,122	25	1	32,373	16,230
2	26	-32,306	-14,879	26	2	32,306	15,976
3	27	-32,497	-14,971	27	3	32,497	16,081
4	29	-19,985	-9,405	29	4	19,985	10,151
5	30	-20,105	-9,534	30	5	20,105	10,292
6	31	-19,912	-9,582	31	6	19,912	10,329
10	16	12,079	3,889	16	10	-12,063	-4,690
11	17	12,106	3,965	17	11	-12,090	-4,768
12	18	11,943	4,030	18	12	-11,926	-4,833

10	22	12,317	5,404	22	10	-12,292	-6,470
11	23	12,230	5,382	23	11	-12,207	-6,452
12	24	12,103	5,536	24	12	-12,077	-6,610
13	19	6,511	1,803	19	13	-6,509	-2,090
14	20	6,437	1,662	20	14	-6,436	-1,950
15	21	6,466	1,749	21	15	-6,465	-2,037
13	22	4,002	0,986	22	13	-4,001	-1,568
14	23	3,912	0,880	23	14	-3,911	-1,463
15	24	3,974	0,972	24	15	-3,973	-1,555
16	19	4,617	3,748	19	16	-4,614	-4,470
17	20	4,489	3,649	20	17	-4,487	-4,373
18	21	4,444	3,785	21	18	-4,440	-4,508
19	22	0,996	0,186	22	19	-0,996	-0,626
20	23	0,924	0,139	23	20	-0,924	-0,579
21	24	0,988	0,203	24	21	-0,988	-0,643
7	33	-3,966	-6,288	33	7	3,969	5,701
8	34	-4,024	-6,332	34	8	4,028	5,745
9	35	-3,837	-6,442	35	9	3,841	5,856
33	36	-10,047	-8,021	36	33	10,047	8,272
34	37	-10,074	-8,038	37	34	10,075	8,292
35	38	-9,881	-8,178	38	35	9,880	8,428

CONCLUSIONS

1. For the investigation of non-symmetrical steady-state and transition modes of complex energy systems, phase coordinate models of system elements (synchronous generator, transformer, power transmission line, load) were developed and the algorithm of using these models in the software was given. It has been shown that when reporting non-symmetrical quasi-decided modes in phase coordinates, it is not appropriate to accept the load, unlike the unilinear schemes. When the loads on the phases are unevenly distributed, the voltages on them are not the same. Therefore, during such reports, it is suggested to consider loads in the form of constant conductance of each phase.

2. The proposed models of system elements can be used for the study of any type of longitudinal-transverse damage, complex non-symmetrical quasi-steady regimes, short-circuit transition processes (without preliminary calculation of short-circuit shunts) in phase coordinates. The dialogue software complex developed on the basis of the proposed models can be applied during the management of modes in operative-dispatcher management in the case of any type of automation.

3. Reports were made for the three-phase short-circuit mode in the phase coordinates of the synchronous generator scheme operating in the electric network for the cases without and with load currents. The coincidence of the change curves of experimentally obtained currents and the reported results shows the adequacy of the proposed models, the methodology and algorithm developed on its basis.

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BALANCE OF ELECTRICAL ENERGY IN ELECTRICAL NETWORKS AND ANALYSIS OF ACTUAL LOSSES

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Abstract: Electricity as a commodity has unique characteristics. So, since it is not possible to store it in large volumes, the buying and selling processes cause more difficulties compared to other commodities. Delivery of electricity from production to consumption in a very short time (tenth of a second), transmission and distribution networks having a complex infrastructure is one of the main reasons for the inevitable technical losses of electricity. Available the problem does not end there. If electricity is not metered during its short journey from production to consumer, it causes additional losses. Due to the improper use of electricity and the ineffective management of transmission and distribution networks, not only technical losses occur at the stages from production to consumption, but also non-technical, i.e., commercial losses. Despite the fact that a lot of work has been done to seriously reduce these losses in recent years , this is still the case remains an important problem. Thus, in 2021, 575.0 million kV of unbalance, i.e. losses exceeding the normative technical loss, occurred in the regional networks of "Azerishiq" OJSC. The conducted studies show that reducing these losses to the level of normative technical losses, i.e. up to 8.8%, is economically more efficient than putting new production capacities into use.

At a time when energy security is the guarantor of the independence of countries, in connection with the transition to a liberal market economy, bringing the losses to the minimum level during the transmission and distribution of electricity is one of the most important tasks facing the states.

Keywords: distribution networks, energy balance, actual losses, technical losses, commercial losses, load losses, conditional-stable losses, climatic losses.

ELEKTRİK ŞƏBƏKƏLƏRİNDƏ ELEKTRİK ENERJİSİNİN BALANSI VƏ FAKTİKİ İTKİLƏRİN TƏHLİLİ

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Annotasiya: Elektrik enerjisi bir əmtəə olaraq unikal xüsusiyyətlərə malikdir. Belə ki, onun böyük həcmlərdə saxlanılması, yəni anbarlaşdırılması mümkün olmadığından alış-satış prosesləri digər əmtəələrə nisbətən daha çox çətinliklər yaradır. Çox qısa bir vaxt ərzində (saniyənin onda biri) elektrik enerjisinin istehsaldan istehlaka qədər çatdırılması, ötürücü və paylayıcı şəbəkələrin mürəkkəb infrastruktura malik olması elektrik enerjisinin texniki itkilərə məruz qalmasını qaçınılmaz edən əsas səbəblərdən biridir. Mövcud problem bununla da bitmir. Elektrik enerjisi istehsaldan istehlakçıya qədər qısa zaman kəsiyində keçdiyi yolda ölçülməzsə, bu da əlavə itkilərə

səbəb olur. Elektrik enerjisindən düzgün istifadə edilməməsi, ötürücü və paylayıcı şəbəkələrin səmərəli idarə edilməməsi səbəbindən istehsaldan istehlaka qədər olan mərhələlərdə nəinki texniki itkilər, hətta əlavə olaraq qeyri-texniki, yəni kommersiya itkiləri də baş verir. Bu itkilərin son illərdə ciddi olaraq azaldılması istiqamətində bir çox işlərin görülməsinə baxmayaraq, bu hələ də mühüm bir problem olaraq qalır. Belə ki, “Azərişıq” ASC-nin region şəbəkələrində 2021-ci ildə 575,0 mln kVs qeyri-balans, yəni normativ texniki itkidən artıq itkilər baş vermişdir. Aparılan araşdırmalar göstərir ki, bu itkilərin normativ texniki itkilər səviyyəsinə, yəni 8,8%-ə qədər endirilməsi yeni istehsal güclərinin istifadəyə verilməsindən iqtisadi cəhətdən daha səmərəlidir.

Enerji təhlükəsizliyinin ölkələrin müstəqilliyinin təminatçısı olduğu bir dövrdə, liberal bazar iqtisadiyyatına keçidlə əlaqədar, elektrik enerjisinin ötürülməsi və paylanması zamanı itkilərin minimum səviyyəsinə çatdırılması dövlətlər qarşısında duran ən mühüm vəzifələrdən biridir.

Açar sözlər: paylayıcı elektrik şəbəkələri, enerji balansı, faktiki itkilər, texniki itkilər, kommersiya itkiləri, yük itkiləri, şərti-stabil itkilər, klimatik itkilər

As a result of the reforms carried out under the leadership and initiative of the President of the Republic of Azerbaijan Ilham Aliyev, in accordance with the strategy of the founder of our independent state, National Leader Heydar Aliyev, aimed at the dynamic development of the country's economy, the industrial and socio-economic potential of our republic has been further developed and diversified, and high achievements have been achieved in all areas of the economy. the economic security of our sovereign state has been ensured.

The recent global economic crisis has had an impact on the electricity sector as compared to other sectors. It is for this reason that the constant attention of the President of the country directed to the electric power sector as a whole, the implemented reforms, especially in the territories liberated from occupation, which have great economic potential and productive conditions. The successful implementation of the "Smart City", "Smart Village" and "Green Energy" projects based on the application of advanced innovations, modern and digital technologies will allow Karabakh economic region to become one of the most developed regions of our country in a short time. As a result of the rapid socio-economic development in the country, new power centers are being created to meet the electricity demand of newly created industrial enterprises, cultural and social objects, agriculture and other infrastructures, distribution networks are being rebuilt based on new technologies and in accordance with international standards, circular electricity the number of networks is increased, immediate and necessary measures are taken in the direction of efficient delivery of electricity to each consumer. Legislation in the field of electric energy is constantly being improved, structural and personnel changes are being made.

The government's attention to transmission and distribution networks is constantly increasing. Reconstruction works are proceeding rapidly. However, despite this, the total volume of losses in our country *(commercial and technical losses)* is still higher than the level of the corresponding indicator of developed countries. In European countries, this rate is 6%. Therefore, the amount of electricity consumed must be monitored, measured and calculated. One of the most important methods used for this process is the balance method. The electric energy balance is the basis for planning and optimizing power plant operating modes, fuel reserves, equipment maintenance schedules, electricity transmission, distribution and sales service tariffs.

In the electric network means the equality of the electric energy supplied to the electric network (wholesale and retail market subject) and the electric energy sold to consumers, taking into account the actual losses for the transmission and distribution of electric energy and the production needs of the network organization.

The amount of actual losses is defined as the difference between the amount of electricity supplied to the grid from other networks or electricity producers and the amount of electricity consumed by subscribers connected to the grid, taking into account the electricity transmitted to other grid companies.

The actual losses for the transmission and distribution of electricity through networks are the most important indicator of the economic efficiency of the operation of networks, an indicator of the state of the entire energy system, and a clear indicator of the interrelationship of the efficiency of energy sales activities.

Liberalization of the electric power system and utility sector are carried out in our country, the creation of a large number of structural units, companies, distributors, regional and wholesale companies, depending on the technology and types of work, makes the task of forming the structural components of the balance of actual losses even more urgent. Thus, it significantly increases the requirements for the reliability of the balance statements, it requires the preparation and approval of normative-legal documents regulating the procedure for determining the balance in electric networks, as well as the procedure for calculating its structural components. The importance of solving these problems and the complexity of the work can be explained as follows. When the distribution network receives electricity from wholesale, it is obliged to compensate (pay) taking into account the actual losses of electricity in its network. In other words, the distribution network is obliged to pay for the energy it buys but cannot sell, that is, it actually loses it. Therefore, the value of normative technological losses of electric energy should be consider and taken into account while calculating the tariff for electricity transmission, distribution and sale services. If the actual losses in the distribution and transmission network companies are greater than the normative technological losses, economic efficiency cannot be achieved in these networks. Thus, distribution and transmission networks pay for all actual losses, receive compensation in the amount of the value of normative technological losses of electricity *(taken into account in the tariff),* endure financial losses due to "excessive" losses of electricity and operate at a loss . The "excess" of electricity losses is due to errors in the metering system, incomplete accounting of consumed electricity, cases of theft, low ability of consumers to pay, ineffective control mechanisms to reduce electricity losses in networks and many other reasons. [1]

That is why the main task of the transmission and distribution networks is to accurately determine the electrical energy balance and the structural components of the balance, including the information about the consumed electrical energy, i.e. to increase the validity and reliability of the calculation of the actual losses.

In order to determine the role of balance sheets and the amount of actual losses in the energy systems of countries, let's consider the indicators of our republic, the Russian Federation and some former Soviet Republics, as well as several foreign countries. Table 1 shows the dynamics of electricity losses in the power grids of the Russian Federation [11].

Table 1

The dynamics of electricity losses in the power grids of the Russian Federation

Balance indicators	Unit of measurement	1994	1995	2000	2004	2005	2008	2010	2015	2020
Produced electricity	billion kW	875,9	860	876	931.9	953.1	1040.38	1037,7	1049.9	1089.67
Specific consumption of power plants	billion kW	61.7	58.6	59.9	59.4	65	67.4	64, 2	67.01	69.59
Purchased electricity (import)	billion kW	22.2	18.4	10.2	12.2	10.1	3.11	2.1	8.2	1,378
Electricity supplied (export)	billion kW	41.7	38	22.8	19.8	22.5	20.74	19.5	18.2	12,11
Released to the network	billion kW	794.7	781.8	803.5	864.9	875.7	955.35	956.1	972.89	1009.35
Consumed electricity	billion kW	707.6	698.3	701.9	752.2	763.1	846.10	851.1	859.33	905.8
Electricity losses	billion kW	79	83.5	101.6	112.6	112.6	109.24	104.97	113.5	103.5
	%	9.94	10.68	12.64	13.02	12.86	11.43	10.98	11.67	10.25

It can be seen from Table 1 that, while the electricity supplied to the network increased by 7.19% for the period 1994-2004, the losses increased by 37.64% in 10 years. Since 2005, a downward trend has been observed.

Now let's analyze the information about the electricity consumption and losses of several former Soviet Republics, which I obtained from the official website of the "International Energy Agency" (Table 2).

Table 2

Data on consumed electricity and losses in CIS countries

	2000		2005		2010		2015		2020	
	Consumed energy, M Watts	**Loss, %**	**Consumed energy, M Watts**	**Loss, %**	**Consumed energy, M Watts**	**Loss, %**	**Consumed energy, M Watts**	**Loss, %**	**Consumed energy, M Watts**	**Loss, %**
Ukraine	159,955	18.08	175.35	13,34	178,313	11.49	152,348	7.7	133,497	10.4
Belarus	24,537	13.06	29,107	11.74	32.81	10.82	32,056	12.1	35,936	11.4

Kazakhstan	48,621	13.96	64,169	10,24	78.09	8.03	86,696	14.01	103,597	18.5
Georgia	7,271	16.82	7,143	15.60	9,985	10.89	10,605	6.6	11,609	7.3
Uzbekistan	44,323	9.08	46,974	8.84	49,266	8.82	54,552	8.8	61,046	8.8
Kyrgyzstan	15,708	25,39	14,637	34,48	11,929	24.09	12,803	20.2	14.84	15.4
Tajikistan	13,983	15.04	16.92	16.07	16,269	14,18	16,982	14,10	19,906	14.0

Table 3

Information about consumed electricity and losses in foreign countries

	2010			**2015**			**2020**		
	Consumed energy, M Watts	**Loss, M Vts**	**Loss, %**	**Consumed energy, M Watts**	**Loss, M Vts**	**Loss, %**	**Consumed energy, M Watts**	**Loss, M Vts**	**Loss, %**
Belgium	90 251	4 283	4.75	86 917	3 815	4.39	83 117	3 444	4.14
Austria	65 422	3 350	5.12	67 050	3 466	5.17	66 911	3 191	4.77
Czechia	62 559	4 466	7,14	62 740	4 066	6.48	63 271	4 117	6.51
Denmark	35 737	2 624	7.34	33 832	1 765	5.22	34 194	1 573	4.60
Finland	87 720	2 761	3.15	82 490	2 434	2.95	81 869	3 021	3.69
France	506 988	35 414	6.99	484 187	36 140	7.46	459 578	35 893	7.81
Germany	570 840	23 973	4.20	553 955	25 605	4.62	525 180	26 939	5.13
Greece	59 058	3 782	6.40	57 340	4 895	8.54	52 315	3 256	6.22
Hungary	39 807	3 800	9.55	41 836	3 695	8.83	44 591	3 139	7.04
Ireland	27 622	2 098	7.60	27 768	2 084	7.51	30 832	2 313	7.50
Italy	330 453	20 570	6.22	316 897	19 717	6.22	301 755	17 760	5.89
Estonia	8 477	1 047	12.3	8 136	697	8.57	8 588	404	4.70
Latvia	6 942	725	10.4	6 914	450	6.51	7 009	381	5.44
Lithuania	10 316	989	9.59	10,960	793	7.24	11,975	951	7.94
The Netherlands	117 600	5 633	4.79	114 651	5 264	4.59	116 491	5 059	4.34
Norway	130 100	9 554	7.34	127 647	7 469	5.85	133 180	8 909	6.69
Poland	141 275	11 851	8.39	149 461	10 534	7.05	158 080	9995	6.32
Portugal	54 893	4 280	7.80	51 746	4 894	9.46	51 551	4 501	8.73

Slovakia	25 936	856	3.30	26 737	1 363	5.10	23 341	1 571	6.73
Slovenia	13 045	982	7.53	13 758	864	6.28	11 360	849	7.47
Spain	278 160	27 400	9.85	265 098	26 509	10.0	262 409	25 631	9.77
Sweden	147 194	10 561	7.17	136 263	6 988	5.13	135 287	10 434	7.71
Switzerland	64 157	4 372	6.81	62 787	4 540	7.23	59 894	4 190	7.00
England	364 395	26 884	7.38	371 954	28 719	7.72	313 760	26 323	8.39
Turkey	202 272	30 222	14.9	253 841	36 528	14.3	292 070	29 126	9.97
Australia	236 472	16 381	6.93	234 756	14 296	6.09	250 020	8 933	3.57
New Zealand	43 446	3 101	7,14	42 895	2 902	6.76	43 768	2 755	6.29
Canada	559 794	48 659	8.69	578 723	33 263	5.75	565 814	33 650	5.95
America	4 155 366	260 999	6.28	4 150 687	255 322	6.15	4 057 937	197 969	4.88
Mexico	263 385	44 252	16.8	297 107	40 640	13.6	334 805	31 633	9.45
Korea	476 729	18 034	3.78	524 141	17 979	3.43	557 463	18 433	3.31
Japan	1 102 998	47 917	4.34	1 025 301	41 162	4.01	993 136	44 194	4.45

The loss percentages shown in this table are not the actual losses, but rather the indicators of the normative technical losses (technological consumption) used in all former Soviet countries (approved by the Cabinet of Ministers of the Republics). The actual losses are not calculated, the balance of the energy system is drawn up formally.

In table 3 below, let's consider the tables about the consumption and losses of electricity prepared by the International Energy Agency based on the data provided by foreign countries [12].

In Austria, the Czech Republic, Finland, France, Norway, Portugal and Sweden, electricity losses are determined by the balance method as the difference between electricity delivered to the grid and consumption, i.e. actual losses.

In the table 4-6 below, let's consider the comparative tables of "Azerishiq" JSC for the years 2016-2021 on the purchased, sold and actual losses [14].

Table 4

Comparison of actual losses of "Azerishiq" OJSC Baku RETSI for the years 2016 - 2021

Years	**Purchased Electricity**	**Total Sold Electricity**	**Actual losses**	**Normative technical requirements**	**Commercial losses**

	kW	kW	kW	%	kW	%	kW	%
2021	9 220 282 598	8 771 638 200	448 644 398	4.87%	673 205 889	7.30%	-224 561 491	-2.44 **%**
2020	8 430 181 864	8 024 691 120	405 490 744	4.81%	631 658 089	7.49%	-226 167 344	- 2.68 **%**
2019	8 978 613 450	8 496 744 331	481 869 119	5.37%	708 007 231	7.89%	-226 138 112	- 2.52 **%**
2018	8 953 873 311	8 338 920 597	614 952 715	6.87%	714 485 575	7.98%	-99 532 860	- 1.11 **%**
2017	8 739 055 170	8 163 777 311	575 277 860	6.58%	703 059 507	8.05%	-127 781 647	- 1.46 **%**
2016	8 963 210 418	8 221 704 720	741 505 698	8.27%	737 086 374	8.22%	4 419 324	0.05 **%**

Table 5

Comparison of actual losses in the regions of "Azerishiq" OJSC for the years 2016 - 2021

Years	**Purchased Electricity**	**Total Sold Electricity**	**Actual losses**		**Normative technical requirements**		**Commercial losses**	
	kW	**kW**	**kW**	**%**	**kW**	**%**	**kW**	**%**
2021	10 542 648 155	8 911 156 677	1 631 491 478	15.48	1 058 462 211	10.04	573 029 267	5.44
2020	10 104 858 601	8 427 708 065	1 677 150 535	16.60	1 025 037 138	10,14	652 113 398	6.45
2019	10 056 771 364	8 341 616 874	1 715 154 489	17.05	1 131 268 031	11.25	583 886 459	5.81
2018	9 831 736 544	7 978 805 867	1 852 930 677	18.85	1 117 088 355	11.36	735 842 322	7.48
2017	9 848 611 369	7 600 048 088	2 248 563 280	22.83	1 128 300 408	11.46	1 120 262 872	11.37
2016	10 293 253 174	7 824 095 646	2 469 157 528	23.99	1 196 923 069	11.63	1 272 234 458	12.36

Table 6

Comparison of actual losses in the networks of "Azerishiq" OJSC for the years 2016 - 2021

Years	**Purchased Electricity**	**Total Sold Electricity**	**Actual losses**		**Normative technical requirements**		**Commercial losses**	
	kW	**kW**	**kW**	**%**	**kW**	**%**	**kW**	**%**
2021	19 762 930	17 682 794	2 080 135	10.53	1 731 668	8.76	348 467	1.76

	753	877	876		100		776	
2020	18 535 040 465	16 452 399 185	2 082 641 280	11,24	1 656 695 227	8.94	425 946 053	2.30
2019	19 035 384 814	16 838 361 205	2 197 023 608	11.54	1 839 275 261	9.66	357 748 347	1.88
2018	18 785 609 856	16 317 726 464	2 467 883 392	13,14	1 831 573 930	9.75	636 309 462	3.39
2017	18 587 666 539	15 763 825 399	2 823 841 140	15,19	1 831 359 914	9.85	992 481 225	5.34
2016	19 256 463 592	16 045 800 366	3 210 663 226	16.67	1 934 009 443	10.04	1 276 653 782	6.63

According to experts, the amount of actual losses in 0.4 - 500kV electric networks should not exceed 4-6% of the energy transmitted (received) to the network. For the Russian Federation, this percentage is around 7-9%. In general, the maximum actual losses should not exceed 10 - 12% of the electricity supplied to the network . If the actual energy losses are higher than 10 - 12%, this is usually explained by the presence of extreme losses. As can be seen from the tables, such a situation exists in many countries. [2]

According to the voltage level of electric networks, the limiting relative technological losses of electric energy according to the electric energy released into the network should be as in table 7:

Table 7

Relative technological losses

220 - 500 kV	2 - 4%
110 kV	4 - 6%
35 kV	6 - 8%
6 - 10 kV	8 - 10%
0.4 kV	10 - 12%

Experience shows that most losses occur in the low voltage network, i.e. 10/6/0.4kV networks and It is in those networks that the greatest difficulties in reducing losses occur.

The reasons for this are mainly the followings:

- lack of measuring devices or expired measuring devices of some consumers;
- incorrect readings of balance and consumer meters;
- intentional violation of the meter scheme and the presence of unaccounted, consumed (stolen) electricity;
- methodical reporting due to the absence or failure of meters, voltage and current transformers, etc.

As can be seen from the tables, in recent years, the dynamics of electricity losses in the electricity grids of many foreign countries have been decreasing. During the mentioned period, the losses in the networks of some countries decreased by about 4-5 times due to the installation of modern meters for electricity consumers, improvement of control of electricity consumption, data collection and processing, automation of the management system.

For the Republic of Azerbaijan, these indicators are more encouraging. Thus, the losses in

the city of Baku have been reduced to 7-8 times in recent years, to 5%, that is, to the level of developed European countries. However, the actual loss rates in the regions still remain high.

The connection between the increase of actual losses in the networks and the economic crisis is characteristic both for the Russian Federation and for other former Soviet Republics, which have entered the period of transition from centralized methods of economic management to partial market methods. It is clear that this is due to the weakening of control over electricity consumption in such a period, as well as the increase in the number of thefts of electricity, as well as the deepening of problems due to the decrease in the ability of a significant part of consumers, primarily the population, to pay.

However, the analysis of the dynamics of energy losses both in Azerbaijan and in other former Soviet Republics shows that there is practically no significant reason for the increase in actual losses. The fact that actual losses are still high in the regions of our country can be mainly explained by the following reasons:

- Slight increase in crown losses due to excessive reactive power in 110kV lines during off-load hours;
- increase in the load of low-voltage networks due to the increase in the share of electricity consumption of household subscribers;
- increase in non-technical (theft) losses;
- relative increase and differentiation of wholesale and retail prices of electricity;
- reduction of government subsidies (debt write-off) to electricity grids compared to previous years;
- distribution and transmission networks are responsible for all losses of electricity;
- transfer of low-voltage regional networks, which have not been reconstructed in the last 30 years, to the balance of "Azerishiq" OJSC since 2015, etc.

It is necessary to use not only the best local but also global experience to eliminate these causes with practical measures and reduce the actual losses in the country's energy system to 6% in accordance with the long-term development strategy of the energy sector for the period until 2025. To solve these problems, it is important to assess the actual losses of electricity in transmission and distribution networks, as well as to mobilize resources to reduce these losses. However, in order to estimate losses and reserves, it is necessary to study the stages and structure of the balance of actual losses of electricity, including non-technical (commercial) losses and the factors affecting them in as much detail as possible. It is proposed to establish the stages of electricity balance in distribution networks according to Figure 1:

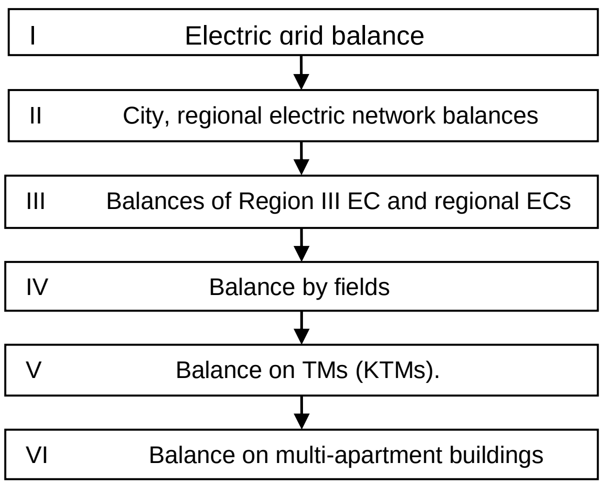
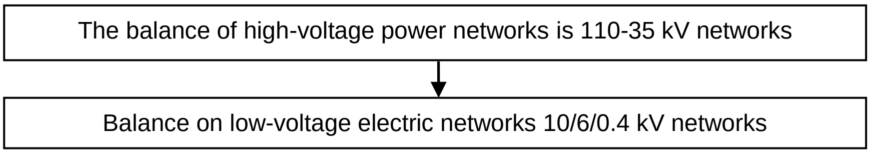
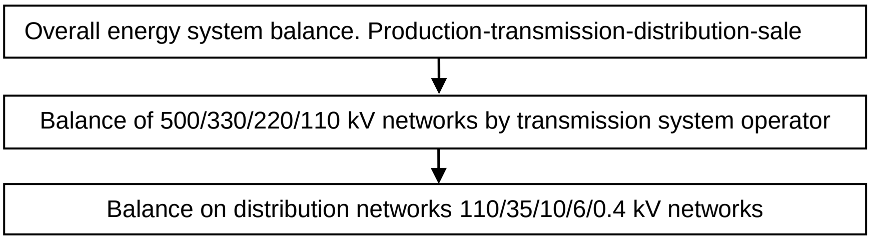


Figure 1. Stages of electricity balance in distribution networks

The balance of electricity by voltage steps should be drawn up in distribution networks as follow



Energy system balance sheets of countries:



The state of the country's energy system is mainly characterized by a single fuel-energy balance model that combines the production and consumption balances of individual energy carriers. According to the definition [2]: "The fuel energy balance is the ratio of the amount of fuel-energy resources received as a result of production or import for an economic object or a certain area, and the decrease due to local consumption or export." Thus, the main task of the fuel-energy balance is to show the real structure of production, transmission, distribution and use of energy resources in a certain area. The fuel-energy balance can be compiled at the state level or at the level of its separate territory (even enterprises, settlements).

Another important problem is the prediction of the fuel-energy balance. In the Republic of Azerbaijan, the fuel-energy balance is prepared and approved by the Cabinet of Ministers for each year. This document also provides forecasts for the next 3 years. We believe that there is a need to further improve the design and forecast scheme of some components of the fuel-energy balance and to further strengthen the control over its implementation. As a result of unclear or non-transparent fuel-energy balance, the following problems may arise in energy policy [2]:

- reduction of technical and economic availability of energy services;
- low economic efficiency due to high losses in the fuel-energy complex (mainly distribution networks);
- decrease in energy security of the country;
- slowdown of economic growth;
- acceleration of inflation;
- the increase in the payment burden in the family budget of energy carriers and the decrease of payments;
- increase in the burden of utility payments and increase in receivables in city and district budgets.

In order to develop a high-quality interconnected fuel energy balance and forecasts, systematically integrated balances should be drawn up at all levels, from bottom to top, in all areas and enterprises that are components of the balance. To solve this global problem, divide the task into parts is appropriate.

I believe that in the preparation of high-quality electricity balance in electric networks, attention should be paid to 3 problems:

1. Absence of reliable and centrally controlled full accounting of electricity received (received), outgoing (transmitted to other networks) and consumed (certified software);
2. Absence of the legislative framework for the formation of the balance in electric networks, as well as the absence of approved legal normative documents-rules;
3. The need to improve the normative-methodological base and terminology used in the formation of the structural components of the electric energy balance and tariff regulation.

In addition, terminology and definitions related to losses and sales of electricity used in management need to be clarified. Thus, there are still ambiguous interpretations in various documents, separate scientific articles, and documents of economic subjects. The lack of an approved terminology in this field prevents integration between separate structures of the economy. Professionals find it difficult to fill out forms and make mistakes.

I should mention that back in 2004, in OJSC "Bakielektrikshabek" (at that time it was managed by the Turkish company "Barmek Holding"), for the first time, a proposal was made by me to calculate the balance of the electricity consumed in the building by installing a balance meter in the distribution box at the entrance of multi-storey buildings. This was aimed at concretely finding the location of electricity thefts in apartments and acting accordingly. Although there were skeptical approaches to this proposal by Turkish experts, with the help of our local experts, balance reports were drawn up for multi-storey buildings, and later for TM and KTMs, software was developed, and for the first time in our republic, a team of 3 people at "Bakielektrikshabek" OJSC made a balance and a loss investigation department was established. Today, about 200 specialists work in the Purchase and Balance Department at "Azerishiq" OJSC, balance reports are drawn up for regions, cities, districts, areas, TM and KTMs, high and low voltage networks. The 3 problems I mentioned above create difficulties in the more perfect preparation of balance sheets.

I should also mention that the balance sheets of the networks may not coincide with the division of the administrative-territorial units of those cities and regions. The main issue here is the historically formed form-design of networks. The main criterion is that the network balance, at any stage, should be complete, allowing the calculation of network losses, their localization and determination of their nature (type), and the electricity received and transmitted to other networks can be accurately measured . Therefore, it is possible to attribute some villages belonging to another region to the network of the other region or vice versa. Taking into account the complexity of the networks of some districts and cities, it is more efficient to divide them into several networks and to conduct separate balance sheets.

For example, Bilajari ESH, which is part of Binagadi district of Baku city, has been operating as a separate network since 2004 and a separate electricity balance is drawn up. Also, Zira ESH of Khazar region and Mashtaga ESH of Sabunchu region operate independently. Bağlar EŞ, which has no administrative-territorial unit, has been operating separately since 2006 and is almost the most difficult and loss-making farm of the electricity networks around Baku. Designing the networks in this way, drawing up the balance sheets had a great impact on the reduction of the losses of the electricity industry of those regions, the Absheron Peninsula in general.

a)

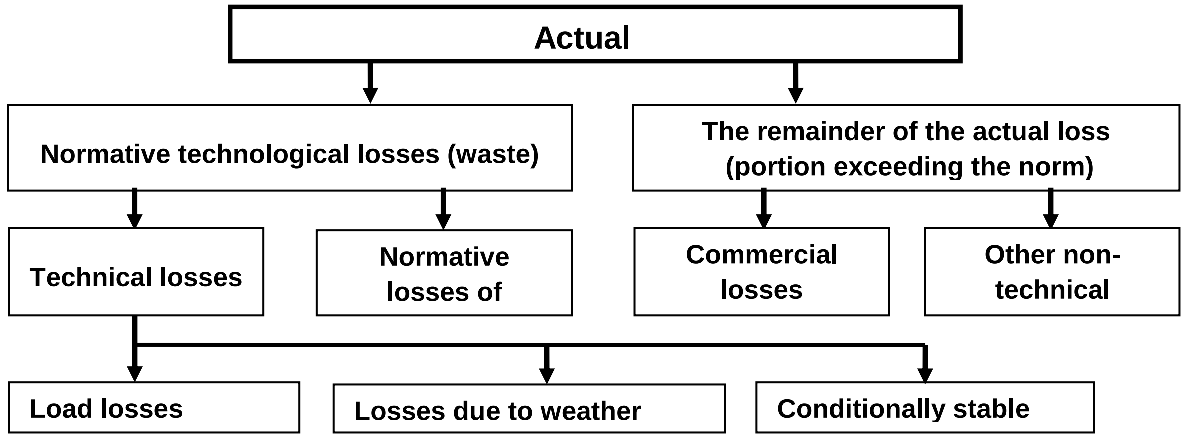
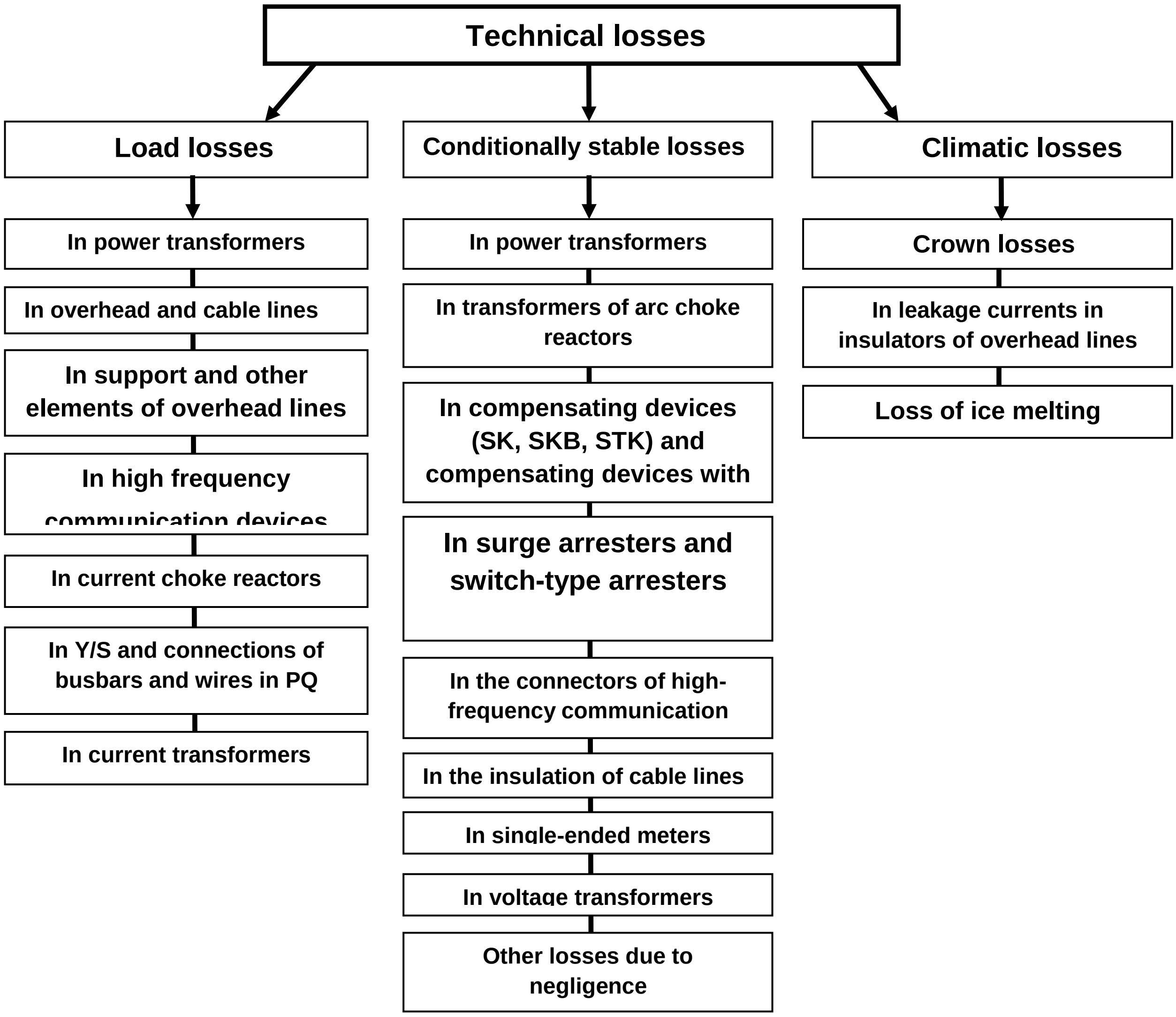


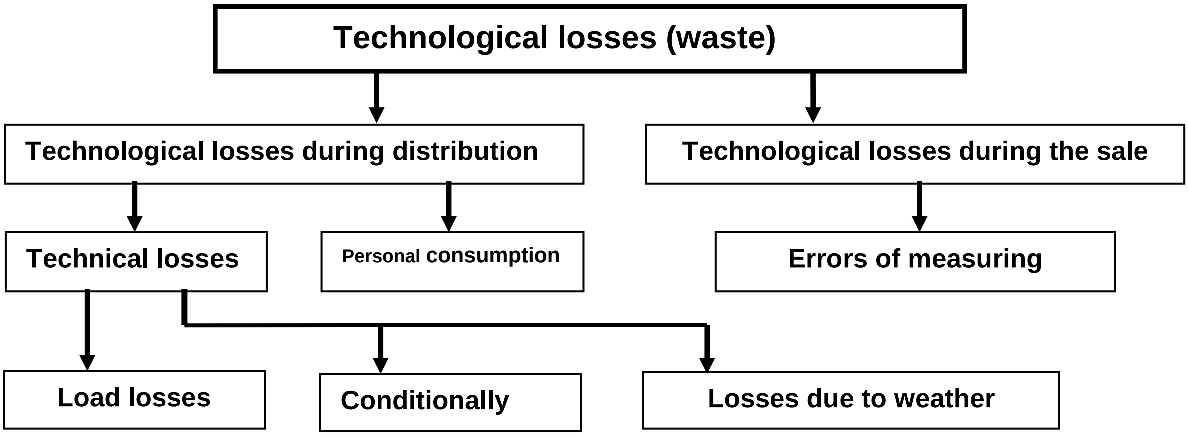
Figure 2. The structure of actual losses of electricity in electrical networks.

b)



All the indicated practical measures made it possible to shape the balance sheet of "Bakielektrikshabek" OJSC starting from 2004, and "Azerishiq" OJSC since 2015, to minimize losses. However, the lack of an official Methodical instruction registered in the Ministry of Justice for the formation of structural components of electricity balances in the country does not allow for a fully reliable assessment of the scale of electricity losses and reduction of electricity losses. This, in turn, complicates the development of feasibility studies and programs for reducing losses during the period of tariff adjustment and in the long term.

Let's consider the structure of the actual losses of electricity in electrical networks



c)

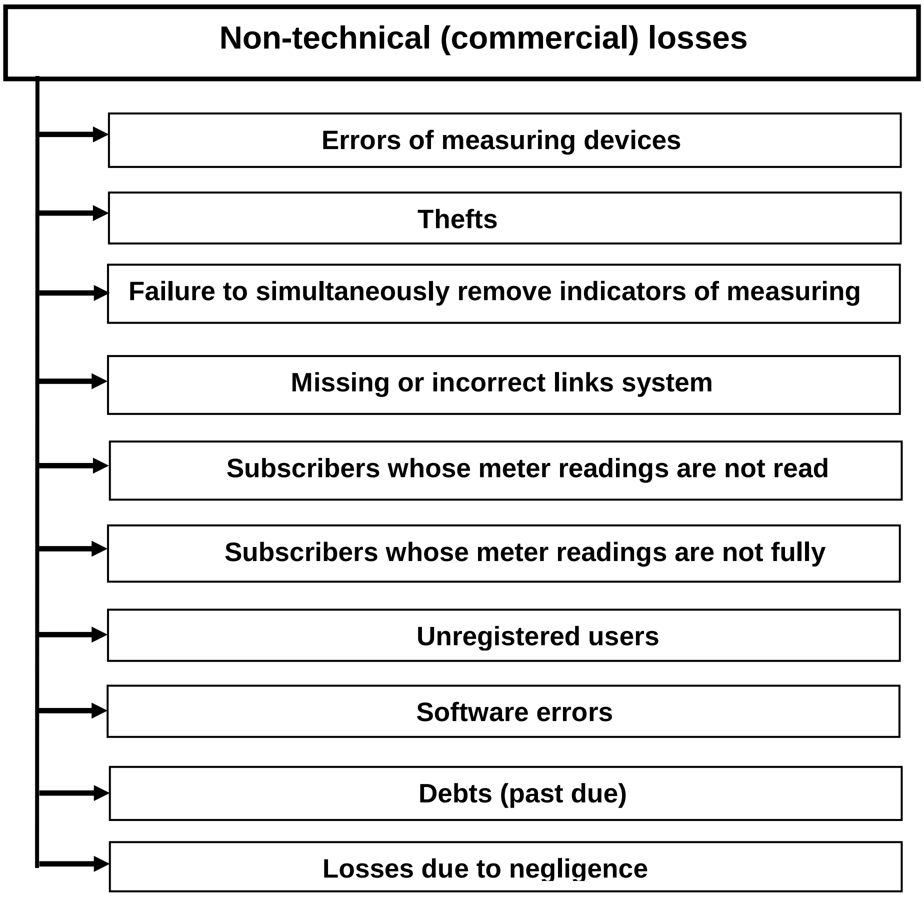


Figure 3. Structure of technical (a), technological (b) and commercial (c) losses

The structure of technical losses of networks has been studied almost enough in our country and substantial scientific researches have been conducted. Figure 3, a, b, c shows the structure of technical, technological and commercial races:

The above tables (schemes) are a traditional approach to actual losses. In simple terms, the actual losses in the distribution system are divided into technical and non-technical. Technical losses are related to energy consumed in conductors and equipment used for energy distribution, depending on the technical characteristics of the distribution network. These losses can occur anywhere in the electrical distribution system. Technical losses in power distribution systems can be divided into losses depending on the intensity of the current in the elements of the electric circuit or

losses independent of the intensity of the current. According to the load condition, technical losses are divided into two parts, depending on the load and independent of the load [9]. Technical loss due to electromagnetic induction also occurs in the core of transformers. There are many methods in the modern literature for accurate calculation of technical losses, even special software is operating at the Azerbaijan Scientific Research and Project Research Energy Institute. [5]

For example, Bilajari ESH, which is part of Binagadi district of Baku city, has been operating as a separate network since 2004 and a separate electricity balance is drawn up. Also, Zira ESH of Khazar region and Mashtaga ESH of Sabunchu region operate independently. Bağlar EŞ, which has no administrative-territorial unit, has been operating separately since 2006 and is almost the most difficult and loss-making farm of the electricity networks around Baku. Designing the networks in this way, drawing up the balance sheets had a great impact on the reduction of the losses of the electricity industry of those regions, the Absheron Peninsula in general.

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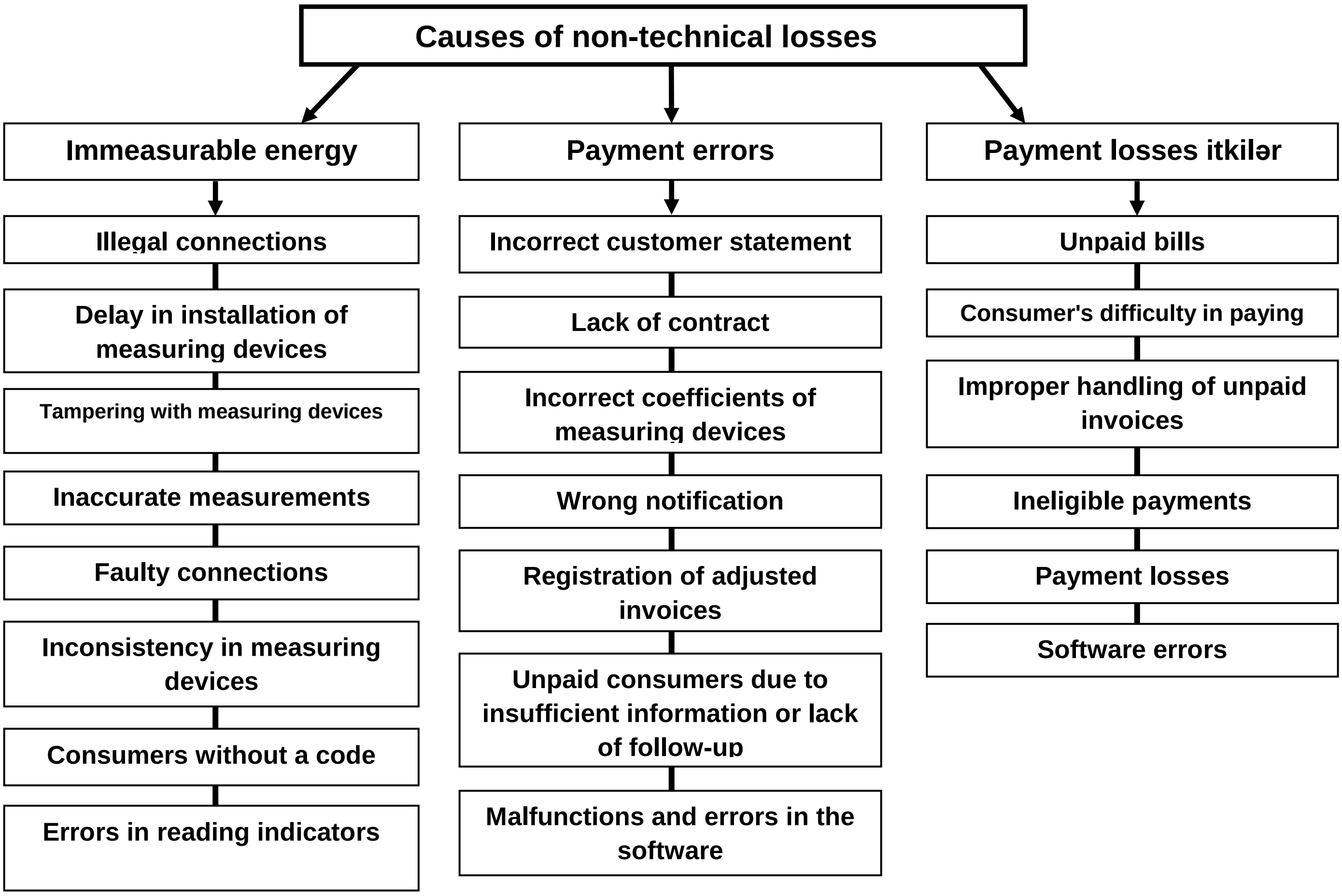

Figure 4. Information on the causes of non-technical losses

Non-technical losses can be defined as the difference between the consumed electricity and the measured electricity or billing amount. We call it commercial losses. Studies of these losses show that the ratio of non-technical losses to total distribution losses cannot be accurately estimated. Commercial losses depend on the technical condition of the networks, the social welfare of the urban population of the region, the organization of network management, the compliance of the staff serving the population, etc. it varies depending on other factors. However, commercial losses can be estimated to be 20-30% of the actual losses, and in some cases up to 50%.

A separate article will be presented on the structure, causes and elimination methods of non-technical losses. Currently, we have tried to summarize the information about the causes of these losses in the following table (Figure 4) [8].

Electricity is an indispensable element of our daily life. As a result of incorrect and inefficient use of this energy, technical and non-technical losses occur at the stages from production, that is, from power plants to the point of consumption. Reducing these losses can allow more efficient use of existing energy systems and thus maintain a balance of demand and supply in the electricity sector.

CONCLUSION.

1. Energy losses in transmission and distribution networks around the world and their monitoring and gradual reduction are becoming more important issues. In a sense, efforts to reduce energy losses are considered equivalent to research to produce energy.
2. The investigation of reporting materials and statistical data from foreign sources shows that the main criterion of the economic efficiency of the production and distribution of electricity is the ratio of the actual losses of electricity to the electricity produced by the generators of power plants.
3. Technical losses, which are a part of actual losses, have been sufficiently researched in our country, relevant scientific works have been written, methods of calculating technical losses have been investigated, and regulations for electric networks have been developed. However, it is impossible to accurately calculate non-technical losses by mathematical methods. Application of balance sheets in transmission and distribution networks, specification of its structure and components, allows determination of actual losses, as a result, non-technical losses.
4. Carrying out balance reports from A to Z on all stages allows to localize the actual losses, predict the presence of commercial losses in specific 10/6/0.4kV lines and MVs and take measures to reduce them.
5. There is a need to study non-technical losses in distribution networks in our country, to investigate the causes of their occurrence, ways to reduce them, to study the effectiveness of methods of preventing electricity theft, to study the relationship between the actual losses and the dynamics, and to make concrete proposals.

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DEVELOPMENT OF A MATHEMATICAL EXPERIMENT METHOD FOR RESEARCH AND OPTIMIZATION OF PROCESS PARAMETERS IN THE SYSTEM OF A HERMETIC PISTON TWO-CYLINDER COMPRESSOR

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ABSTRACT.

The article discusses the features of a mathematical model developed to study the processes in the system of a two-cylinder hermetic piston compressor when it operates in an open cycle and refrigerant - 22. Some results of computational experiments are given that are in good agreement with the literature data.
Keywords: Hermetic piston compressor; mathematical model; process modeling; calculation of flow parameters; explicit difference scheme.

İNTRODUCTİON.

As is known, in order to create refrigeration equipment that meets the requirements of world standards, it is necessary to increase the level of research work using the latest equipment, research methods and processing of their results.

At the Azerbaijan Technical University, a computer method for conducting a mathematical experiment on a set of processes occurring in a refrigeration unit of a household air conditioner, which has a rotary compressor and operates in cold and heat modes, has been developed and implemented; in dynamics, including an improved mathematical model that takes into account the unsteady wave nature of the refrigerant flow in pipelines, hydraulic resistance, variability of physical characteristics of the medium, phase transformations, heat and mass transfer, the influence of moving elements, narrowing and expansion of channels. The model allows for computational research in time and coordinates, and thereby turns the system, as it were, into a “transparent” one [1].

Due to the fact that compressors are widely used not only in air conditioning systems, but also in other refrigeration systems, and they can also be used as compressor units for various purposes, we have developed a methodology that allows us to conduct computational studies of flow parameters in small sealed volumetric systems compressors when operating in an open cycle. In this case, the model simulates the operation of a compressor on a stand to determine air capacity [2].

Studies of the operation of small hermetic compressors (XqRV - 1.75 and XKV - 6) have shown that this technique is quite effective.

The research and accumulated experience made it possible to develop and implement on a modern computer a method for calculating the parameters of processes occurring in the system of a hermetic two-cylinder piston compressor PG - 5 and operating on freon - 22. Technical data and characteristics of the compressor are given in [4].

The choice of such a compressor is due to the fact that it has a relatively large cooling capacity (5.8 kW in "standard" mode), the flow part is similar to the flow part of medium and large compressors, and the multi-cylinder nature allows one to take into account the displacement of processes depending on the angle between the shaft elbows.

The design diagram of the compressor is shown in Fig.1.

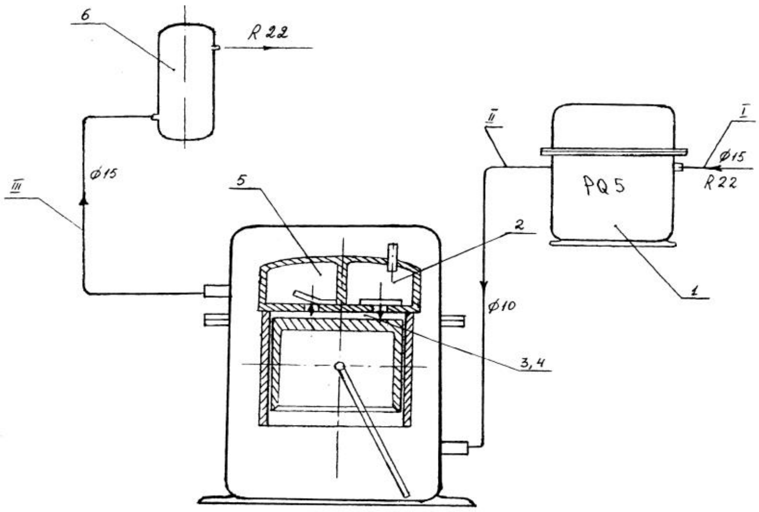


Figure 1. Compressor design diagram.
1 - cavity of the sealed casing; 2.5 – supravalvular cavities of the suction and discharge valves; 3, 4 – cylinder cavities (suction and compression); 6 – receiver; I, II, III – pipelines.

In the developed model, the pressure in the pipelines of the system is determined from the general equations of gas dynamics (equations of motion and continuity) presented in model form [3].

$$\frac{\partial q}{\partial \tau} + b\frac{\partial q}{\partial x} = -f(w) \quad (1)$$

$$\frac{\partial \ell}{\partial \tau} - c\frac{\partial \ell}{\partial x} = f(w) \quad (2)$$

Where, $q = \Phi + w:\ \ell = \Phi - w;\ b = a + w$ (3)

$$c = a - w; \; f(w) = \frac{\xi}{4R} w|w|$$

$$d\Phi = \frac{1}{a\rho} dp \tag{4}$$

The temperatures of the refrigerant flow and the walls of the pipelines were determined from the energy and heat balance equations

$$\rho wf \frac{\partial i}{\partial x} + \rho f \frac{\partial i}{\partial \tau} = \alpha_{\hat{a}} h_{\hat{a}} (\theta_{CT} - T) \tag{5}$$

$$\alpha_{\mathrm{H}} h_H (T_H - \theta_{CT}) - g_m c_m \frac{\partial \theta_{CT}}{\partial \tau} = \alpha_{\hat{a}} h_{\hat{a}} (\theta_{CT} - T) \tag{6}$$

These equations are approximated using an explicit difference scheme:

$$\frac{q_{k,j+1} - q_{k,j}}{\Delta\tau} + \mathrm{b}_{\mathrm{k,j}} \frac{\mathrm{q}_{\mathrm{k,j}} - \mathrm{q}_{\mathrm{k-1,j}}}{\Delta \mathrm{x}} = -\mathrm{f}(\mathrm{w}_{\mathrm{k,j}}) \tag{7}$$

$$\frac{\ell_{\mathrm{k,j+1}} - \ell_{\mathrm{k,j}}}{\Delta\tau} - c_{k,j} \frac{\ell_{k+1,j} - \ell_{k,j}}{\Delta x} = f(w_{k,j}) \tag{8}$$

$$\Phi_{\mathrm{k,j+1}} = \Phi_{k,j} + \frac{P_{k,j+1} - P_{k,j}}{(a\rho)_{k,j}} \tag{9}$$

$$(\rho f w)_{k,j} \frac{i_{k,j} - i_{k-1,j}}{\Delta x} + (\rho f)_{k,j} \frac{i_{k,j+1} - i_{k,j}}{\Delta\tau} = (\alpha_{\hat{a}} h_{\hat{a}})_{k,j} (\theta_{k,j} - T_{k,j}) \tag{10}$$

$$g_m c_m \frac{\theta_{k,j+1} - \theta_{k,j}}{\Delta\tau} = (\alpha_{\hat{a}} h_{\hat{a}})_{k,j} (\theta_{k,j} - T_{k,j}) - (\alpha_H h_H)_{k,j} (T_H - \theta_{k,j}) \tag{11}$$

The stability of calculations and the convergence of solutions were ensured by compliance with the Courant condition:

$$\frac{\Delta\tau}{\Delta \mathrm{x}} \cdot a \le \frac{1}{2} \tag{12}$$

In relations (1) $\div$ (12), w, m/s - is the flow speed; , Φ, m/s - substitute function for bringing the gas dynamics equations into the form of model equations; , a, m/s - speed of sound; b, c - the speed of propagation of the pressure pulse through the pipeline in the forward and reverse directions, respectively; P, Pa - pressure of the working fluid in the flow; , ρ, kg/m3 - density of the

working fluid; R, m - internal radius of the pipe; ξ - coefficient of hydraulic resistance; i , C/kg - enthalpy; $\alpha_{â}$, Wt/m2 K - heat transfer coefficient from the channel wall to the refrigerant flow; α_{H} , Wt/m2 K - heat transfer coefficient from the blown medium to the channel wall; , K - temperatures of the channel wall and working fluid; $h_H, h_{â}$, m2/m - specific outer and inner surfaces of the channel; g_m , kg/m - mass of channel material per unit channel length; c_m, C/kg K - specific mass heat capacity of the channel material; $\tau(sek)$ and x (m) - coordinate and time; and - numbers of steps along the pipeline length and in time, respectively.

To determine the parameters in the cavities of the system, equations of boundary conditions for the compressor and for various cavities were used.

The equations for the boundary conditions of the compressor consist of the equation of motion of the piston, changes in the volumes of the suction and compression cavities, the equations of motion of the suction and discharge valves, etc. These equations are composed similarly to the equations given in the work [1].

When determining the parameters of the working fluid in the cavities of the system, the equation of the first law of thermodynamics for a body of variable mass, the mass balance equation and the equation of state were also used.
The equation of the first law of thermodynamics in differential form is:

$$dQ + dE_1 = \mathrm{dU} + \mathrm{dL} + \mathrm{dE}_2 \tag{13}$$

Mass balance equation

$$dM = dM_{vx} - dM_{vix} \tag{14}$$

Equation of state (Bogolyubov-Mayer equation):

$$\mathrm{Z} = 1 + \sum_{i=1}^{r}\left(\sum_{j=1}^{S}\frac{b_{i,j}}{\tau_j}\right)\rho^i \tag{15}$$

$$\text{Where,}\quad Z = p \cdot 10^{-6}/\mathrm{R}\rho\mathrm{T};\qquad R = 8{,}31437/\mu;\qquad \tau = \frac{T}{T_{kp}} \tag{16}$$

In expressions (13) ÷ (16) dQ - heat imparted to the working fluid from the outside; dE_1 - the amount of thermal energy entering the working space (through the outlet valve, leakage through cracks), dU - change in the internal energy of the working fluid; dL - external work on the working fluid; dE_2 - the amount of energy lost from the working space (through the discharge valve and leakage through the cracks), dM - change in the mass of the refrigerant in the working cavity;

dM_{vx} - mass of the working fluid entering the working cavity; dM_{vix}- mass of the working fluid displaced from the working cavity; T, K - temperature; P, Pa - pressure; μ - molecular mass; ρ, g/sm3 - density; Tkr, K - critical temperature; $b_{i,j}$ - virial coefficient depending on temperature.

The individual components of equations (13) and (14) are calculated using similar equations given in work [1], the virial coefficients of equation (15), as well as thermodynamic, thermophysical and heat - mass transfer characteristics and gasdynamic resistances are determined using the formulas given in [5].

The final calculated parameter in the model is the volume flow through the nozzle in the receiver (Fig. 1). The diameter of the nozzle is determined from the condition of equality of the actual volumetric cooling capacity of the compressor and the flow rate through the nozzle.

The mass flow rate through the nozzle per cycle is determined according to

$$\mathrm{G} = \sum_{i=1}^{n} \mu \cdot f_{æ} w_{æ} \rho_p \Delta\tau \text{, kq/sec} \tag{17}$$

and the actual volumetric capacity of the compressor

$$V_{ä} = \frac{1}{\tau_{ö}} \cdot \frac{\mathrm{GRT_0}}{\mathrm{P_0}} \quad \mathrm{m^3/sec} \tag{18}$$

Where, $\mu \cdot f_{æ}$ - effective flow area of the nozzle, m2;

$w_{æ}$ - flow velocity leaving the receiver, m/s;

ρ_{p} - density of the working fluid in the receiver, kg/m3;

P_0, T_0 - pressure and temperature of the medium into which the refrigerant flow exits, Pa, K;

R - gas constant of the working fluid, C/kg K;

$\Delta\tau$ - time step, sec;

$\tau_{ö}$ - time of one cycle, sec.

The program was compiled in FORTRAN-e, the calculations were made on a personal computer.

Figure 2 shows the calculated indicator diagram of the compressor when it is operating in the “standard” mode ($t_0 = -15^0\mathrm{C}, \mathrm{t} = 30^0\mathrm{C}$). The diagram also shows graphs of pressure changes in the sealed casing, in the over-valve cavities of the suction and discharge valves and in the receiver [6].

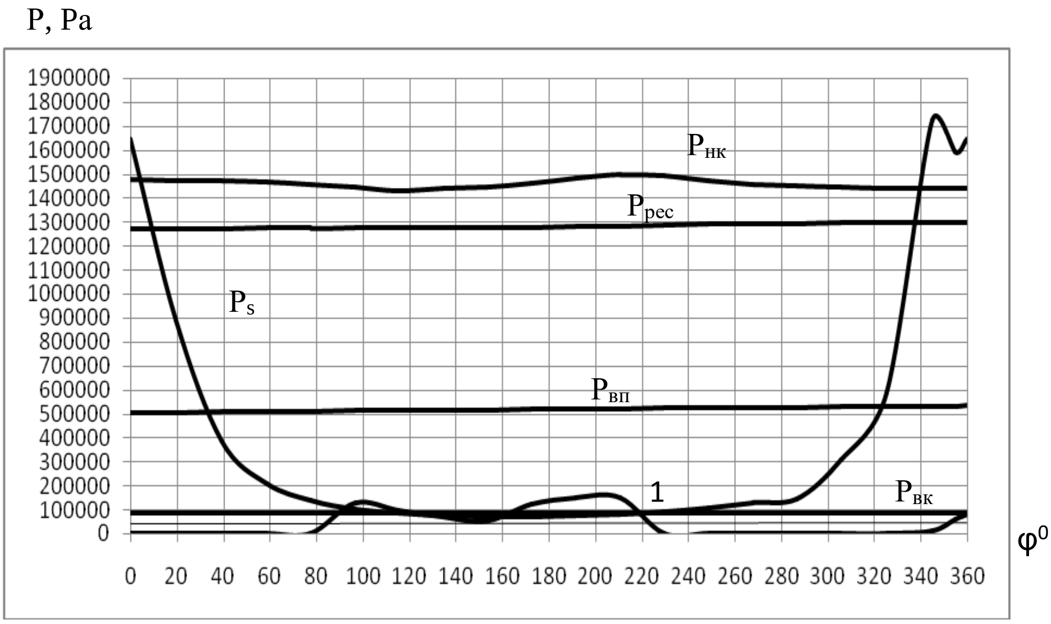


Figure 2. Compressor design indicator diagram.
Rvp, Rvk, Rnk, Pres - pressure in a sealed casing, in the over-valve cavities suction and discharge valves and in the receiver; 1 - traffic schedule suction and discharge valve plates.

As you can see, the indicator chart has a theoretically imaginable form. However, the opening of the suction and discharge valves is delayed, and the closing of the discharge valve occurs during the suction process of the next cycle. Apparently, this is due to the peculiarity of the crank mechanism (uneven movement of the piston) and the low values of the polytropic expansion and compression index for freon - 22, which practically brings these processes closer to isothermal. It should be noted that by optimizing the flow sections of valves and spring parameters, it is not difficult to shift the opening and closing moments of valves in the desired direction.

Figure 3 shows a graph of pressure changes along the III tube (Fig.1), connecting the compressor cavities to the receiver. As can be seen, the intensity of the pressure wave is not great. We carried out calculations of the actual volumetric productivity of the compressor in various modes (within $t_0 = -30 \div 0^0 C$ and $t = 30 \div 55^0 C$) and determined the values of the compressor supply coefficient [7].

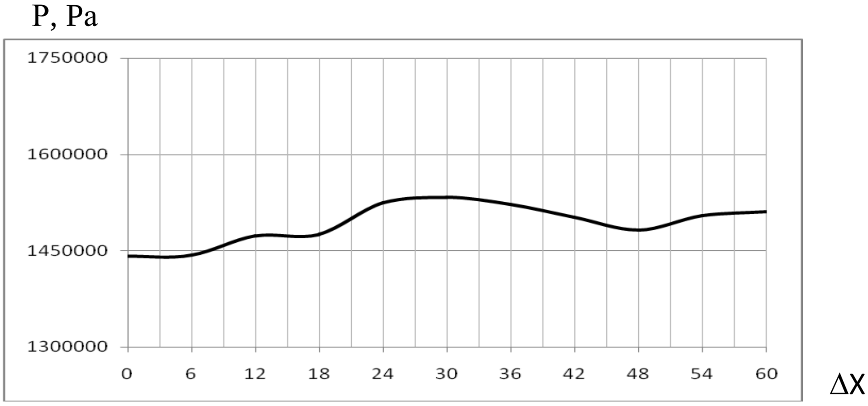
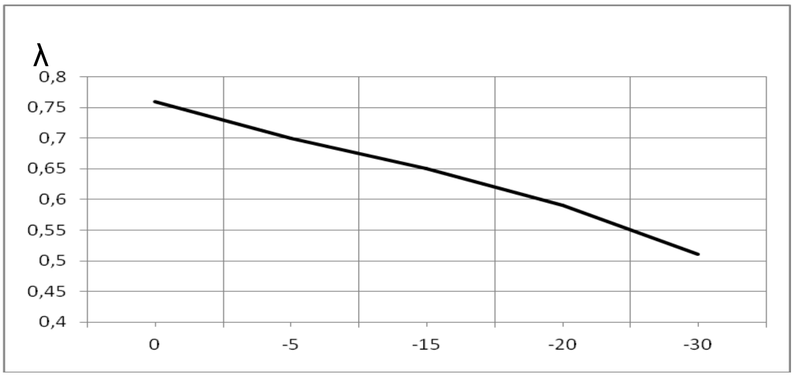


Figure 3. The change in pressure along the III tube at

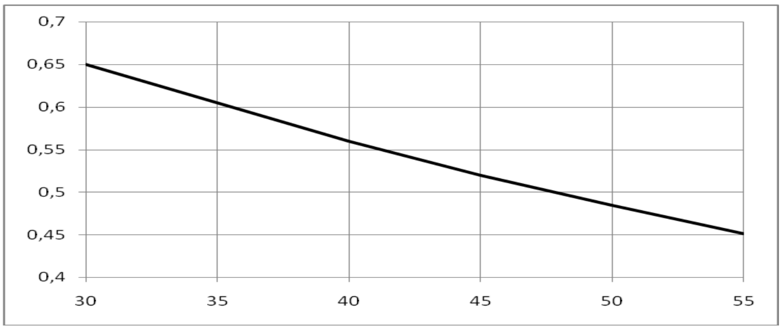
Figure 4 shows graphs of changes in the supply coefficient depending on the boiling and condensation temperature. The results obtained are in good agreement with the literature data [3].



$\lambda = f(t)$ at $t = 30^0 C$

t_0

λ



$\lambda = f(t)$ at $t_0 = -15^0 C$

t

Figure 4. Changing the feed ratio depending on the modes compressor operation.

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More than 85 scientific studies and 1 teaching material, 7 methodical instructions have been published.

EXPERIMENTAL STUDY OF DENSITY OF THERMAL WATER "4-TH SECTİON" OF KHAMAZ DISTRICT OF AZERBAIJAN AT DIFFERENT PRESSURES AND TEMPERATURES

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XÜLASƏ

İşdə (p,ρ,T) asılılıqlarının ölçülməsi zamanı hər bir müvazinət halında atmosfer təzyiqində qrafik ekstrapolyasiya yolu ilə sıxlığın yüksək dəqiqlikli qiymətlərinin alınması məqsədi ilə təzyiqin maksimum dərəcədə mümkün olan aşağı qiymətləri yaradılmağa səy göstərilmiş, alınmış qiymətlər sıxlığın DMA 5000M qurgusunda ölçülmüş qiymətləri ilə müqayisə olunmuşdur. Azərbaycannın Xaçmaz rayonunun “4-cü bölmə” termal suyunun müxtəlif təzyiq və temperaturlarda sıxlığının təcrübi qiymətləri ölçülmüşdür. Öncə təcrübə qurğusunun ölçmə dəqiqliyinin yoxlanılması üçün su, toluol üçün alınmış nəticələrin müxtəlif ədəbiyyatlarda verilmiş məlumatlarla müqayisəsi aparılmışdır. Alınmış təcrübi nəticələr cədvəldə göstərilmiş və hal tənliyi ilə ifadə olunmuşdur.

Açar sözlər: *sıxlıq, təzyiq, temperatur,termal sular.*

SUMMARY

During the measurement of (p, ρ, T) dependences, in order to obtain high-accuracy values of density by means of graphical extrapolation at atmospheric pressure in each case of equilibrium, efforts were made to create the lowest possible values of pressure, the obtained values were compared with the values of density measured on the DMA 5000M device. compared. The experimental values of the density of the "4th division" thermal water of Khachmaz region of Azerbaijan at different pressures and temperatures were measured. First, in order to check the measurement accuracy of the experimental device, the results obtained for water and toluene were compared with the information given in various literature. The obtained experimental results are shown in the table and expressed by the equation of state.

Keywords: *density, pressure, temperature, thermal waters.*

Currently, extensive measures are being taken both within the Republic and internationally to reduce the amount of carbon dioxide emitted into the atmosphere. Great work is being done in this direction in Azerbaijan (including at the Department of Energy Efficiency and Green Energy Technologies of Azerbaijan Technical University). In accordance with the "State Program on the Use of Alternative and Renewable Energy Sources in the Republic of Azerbaijan" approved by the

Decree of the President of the Republic of Azerbaijan dated October 21, 2004, the Ministry of Industry and Energy of the Program the implementation coordinator has been determined [1]. In the State Program, the main directions for the implementation of measures related to the use of the potential of wind energy, as well as solar energy, the hydropower of geothermal waters, mountain rivers and water channels, as well as the energy of biomass, as the most efficient energy sources for our Republic, have been defined.

In addition to the regional fracture in the zone of thermal water distribution, there is also a zone of tectonically disturbed rocks with a branched system of sharply falling (descending) cracks covering the entire Mesozoic layer. The velocity of water is higher in the main drainage channels, i.e., where the transfer of water heat to the surrounding rocks is the least, thus the water has the maximum temperature, and in the zones with many cracks. This is confirmed by the outputs of geothermal sources in the erosion depressions of the intersection of the main sututar zones [2].

The hydrogeological parameters of the discharge zone of thermal waters directly depend on the degree of cracking and the character of the hydrous rocks. The abundance and abundance of gryphons in natural outcrops indicates a well-developed rift.

Geothermal energy resources of the studied region (Khachmaz region) are particularly valuable. Thus, the colorful chemical composition, high healing properties, favorable geographical position of the area create a good basis for their treatment purposes and wide application in various fields of the national economy [2,3].

The analysis of the chemical composition of thermal water of Khachmaz district "4th section" was measured in atomic emission spectrometer with IRIS Intrepid II Optical Emission Cheomotograph inductively coupled plasma [3,4]. The results show that the majority of chemical elements are sodium (Na). Na constitutes approximately 72.41 ÷ 90.12% of all chemical substances in the thermal water of the Khachmaz region of Azerbaijan. In the tables 1-4 shown below, the geographical coordinates of the thermal water of the "4th section" station located in Khachmaz region of Azerbaijan, the temperature at the time of exit from the source and the amount of minerals in the chemical composition are given [3,4]

Geographical coordinates of Khachmaz district "4th section" thermal water and its temperature at the moment of exit from the source

Table 1.

Name of source	Geographical coordinates	Temperature at exit
“Unit 4”	North $41^0 36'17''$ East $48^0 41'54''$	T = 327,15 K

Chemical composition of thermal water of "4th division" of Khachmaz region of Azerbaijan

Table 2.

The amount of minerals in the sample	Al1670	As1890	B2089	Ba2304	Ca3181	Cd2288	Co2286	Cr2055	Cu3247	Fe2599
Section 4, mg/liter	<0.01	<0.01	1.87	0.11	158.0	<0.01	<0.01	<0.01	<0.01	0.02

Table 3.

The amount of minerals in the sample	Hg1849	K7664	Li6707	Mg2790	Mn2939	Mo2045	Na8183	Ni2316	P2136
Section 4, mg/liter	<0.02	18.30	0.16	28.20	0.11	0.02	832	<0.01	<0.01

Table 4.

The amount of minerals in the sample	Pb2203	S1820	Sb2175	Se1960	Si2124	Sr4077	Ti3349	Tl1908	V2924
Section 4, mg/liter	<0.01	37.40	<0.02	<0.02	3.09	9.28	<0.01	<0,05	<0.01

Taking into account the fact that the vibrating tube densimeter device needs to be calibrated with at least two substances for the study of the density of liquids after checking the device's performance, for this purpose, water, toluene are used as the main calibrator. standard) were selected as substances. The results obtained for water and toluene were compared with the information given in the literature. As a result of the comparison, the difference between the obtained values for the density of water and toluene and the information in the literature shows that the estimated errors of the measurements in the device are very small. Obtaining results with a small error and close to each other shows the high accuracy of the created experimental device [4,5].

After the verification experiments on the properties of water and toluene (p,ρ,T) were carried out, the density of the thermal water of Khachmaz district "4th section" of Azerbaijan was measured at high pressure and different temperatures in the experimental facility that works with the vibrating tube densimeter method. . During the measurement of (p,ρ,T) dependences, in each case of equilibrium, an effort was made to create the lowest possible values of the pressure in order to obtain high-precision values of the density by means of graphic extrapolation in the atmospheric

pressure, and the obtained values are the DMA of the density It was compared with the values measured in the 5000M device. The values obtained by different methods agree well within ± 0.02% [3-5]. Researches for thermal water of Khachmaz district "4th division" were conducted at temperatures T=(278.15÷373.15) K and pressures up to p=40 MPa. Experimental indicators obtained on (p,ρ,T) dependencies are given in table 5.

Experimental values of the density of the "4th division" thermal water of Khachmaz region of Azerbaijan at different pressures and temperatures

Table 5.

$\frac{p}{MPa}$	$\frac{\rho}{kq/m^3}$	$\frac{T}{K}$	$\frac{p}{MPa}$	$\frac{\rho}{kq/m^3}$	$\frac{T}{K}$
0.201	1007.44	278.15	0.214	991.53	328.15
5.006	1009.65	278.15	5.006	993.57	328.17
10.006	1011.92	278.16	10.301	995.81	328.16
15.214	1014.26	278.14	15.921	998.17	328.15
20.004	1016.39	278.15	20.152	999.93	328.14
25.301	1018.72	278.16	25.008	1001.94	328.15
29.986	1020.76	278.15	30.102	1004.03	328.13
35.114	1022.97	278.13	35.026	1006.03	328.15
39.997	1025.04	278.15	39.996	1008.03	328.15
0.690	1006.06	288.16	0.302	983.52	343.15
5.061	1007.95	288.11	5.014	985.64	343.17
10.162	1009.96	288.10	10.006	987.85	343.15
15.166	1011.85	288.13	15.308	990.14	343.16
19.942	1014.07	288.11	20.410	992.30	343.15
24.996	1016.13	288.13	25.008	994.21	343.16
30.010	1018.40	288.11	29.998	996.23	343.16
34.744	1020.45	288.13	35.047	982.30	343.15
40.002	1022.67	288.13	39.995	1000.14	343.15
0.798	1002.95	298.19	0.304	974.18	358.15
5.132	1004.77	298.19	5.008	976.40	358.14
9.979	1006.82	298.19	10.009	978.69	358.16
14.879	1009.03	298.14	15.308	981.04	358.15

20.098	1011.23	298.13	20.008	983.07	358.15
25.123	1013.33	298.13	25.021	985.18	358.16
30.022	1015.38	298.12	29.987	987.20	358.17
34.932	1017.28	298.13	35.030	989.19	358.15
39.846	1019.24	298.14	39.994	991.08	358.15
0.385	997.61	313.07	1.393	963.97	373.08
5.158	999.87	313.08	5.416	965.99	373.08
10.079	1002.12	313.08	10.407	968.36	373.08
15.112	1004.32	313.08	15.587	970.77	373.09
19.962	1006.44	313.06	0.420	972.95	373.09
25.287	1008.74	313.06	25.274	974.97	373.09
29.992	1010.62	313.07	30.049	977.01	373.09
35.037	1012.69	313.06	35.201	978.99	373.09
40.130	1014.69	313.08	39.745	980.72	373.10

The obtained experimental results are expressed by the following equation of state:

$$p = A\rho^2 + B\rho^8 + C\rho^{12} \tag{1}$$

Here, coefficients A(T), B(T) and C(T) depend on temperature in polynomial form:

$$A(T) = \sum_{i=1}^{3} a_i T^i,\ B(T) = \sum_{i=0}^{2} b_i T^i,\ C(T) = \sum_{i=0}^{2} c_i T^i \tag{2}$$

Values of coefficients a, b and c in equation (2) are given in table 6.

Tablel 6.

$a_1 = -1.2533813$	$b_0 = 736.75489731$	$c_0 = -488.2859137$
$a_2 = -0.339952\cdot10^{-2}$	$b_1 = -3.43166265$	$c_1 = 3.2130145$
$a_3 = 0.96906297\cdot10^{-5}$	$b_2 = 0.87206243\cdot10^{-2}$	$c_2 = 0.61334197\cdot10^{-2}$

The equation (1) allows to express the experimental values of the dependence of thermal water (p,ρ,T) of "Section 4" with average error of 0.007%, taking into account the values of the coefficients A(T), B(T) and C(T). gives

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